JUNE 1951

Chemical Engineering Progress

PUBLISHED MONTHLY BY THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS

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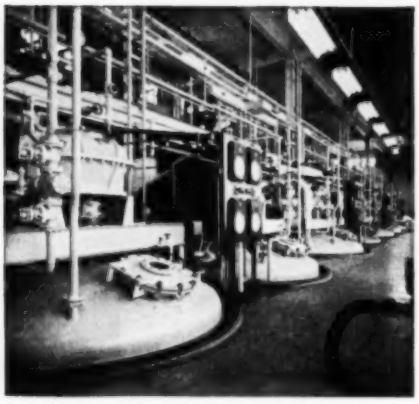
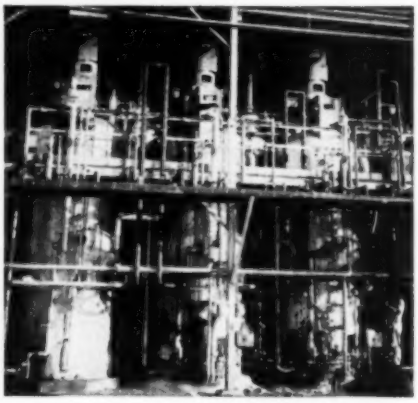


Turbo-Mixer equipped antibiotic fermenters at the Upjohn Company, Kalamazoo, Mich.



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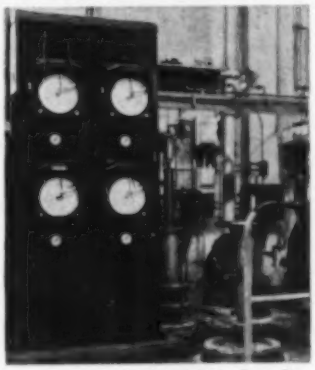

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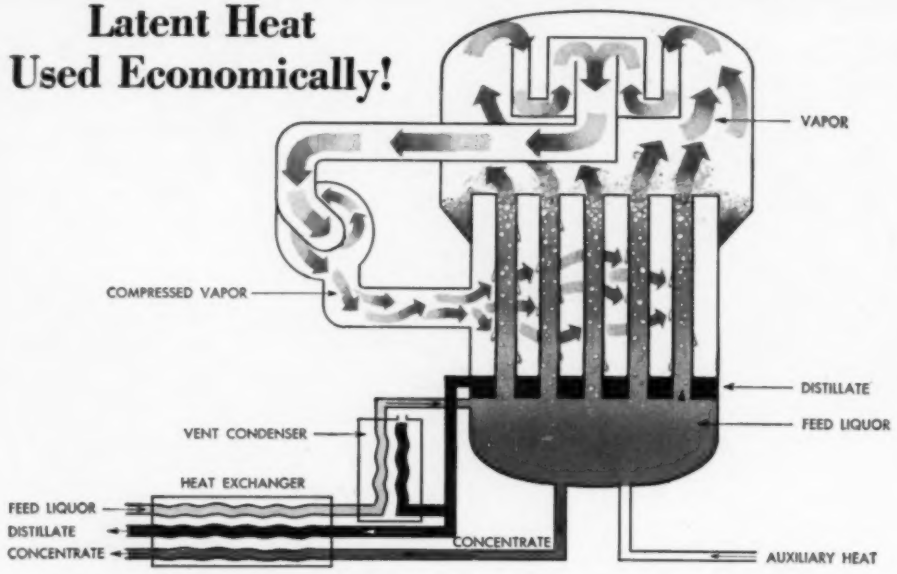

The Merit Of Compression Distillation Lies In The Fact That Latent Heat Is Constantly Being Reclaimed and Utilized . . . Recycling Through The Evaporator

In order to start the cycle of operation, an auxiliary heat source is generally provided through either a direct steam supply, internal combustion engine heat, or directly applied immersion heaters. When the original supply of raw liquid has reached the boiling point, using auxiliary heat, the compressor is started into operation.

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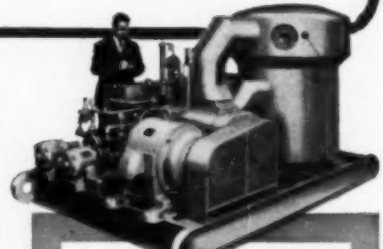

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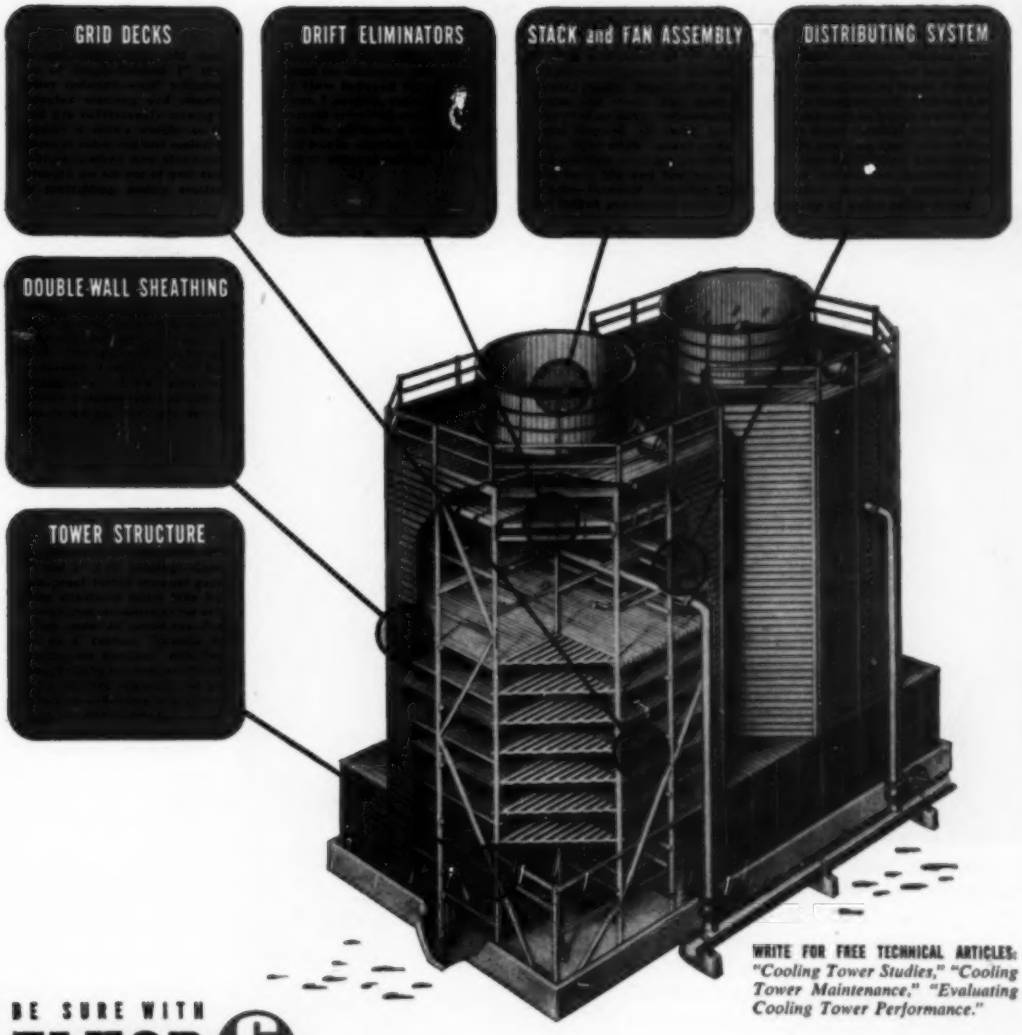

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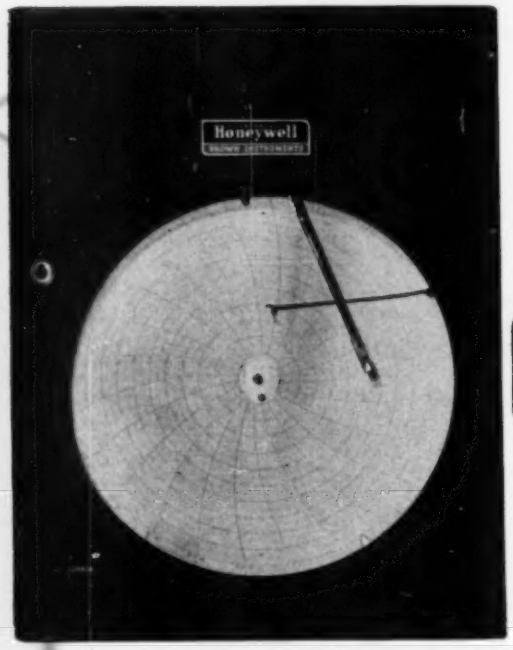

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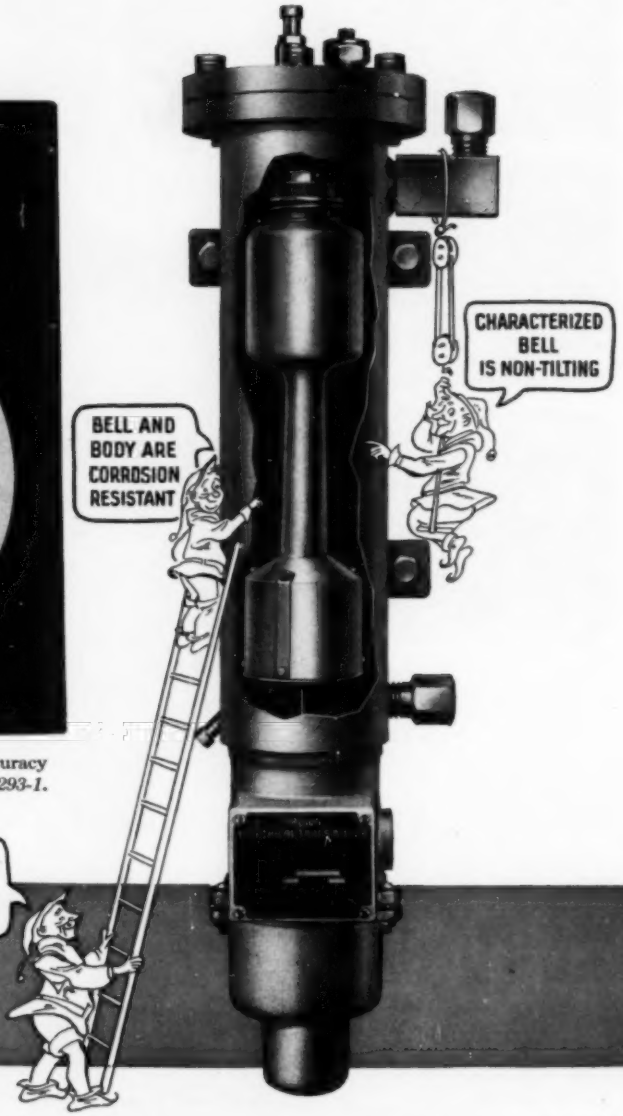

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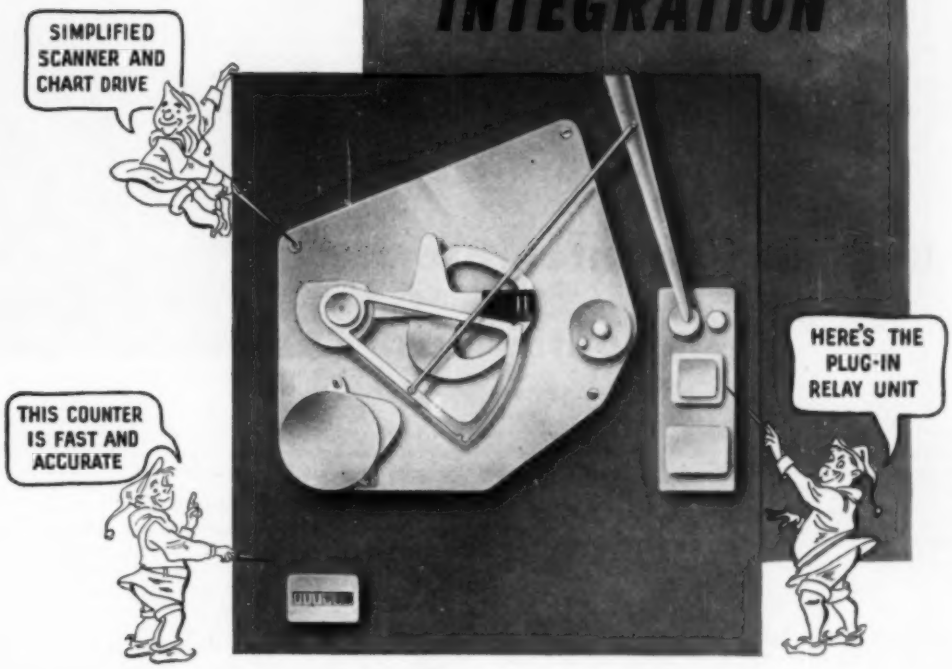

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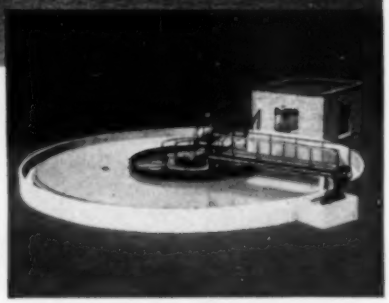

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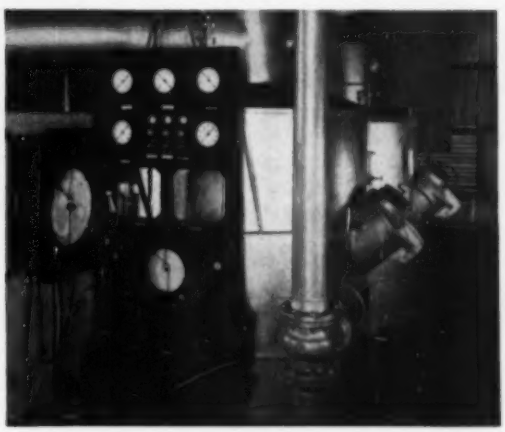

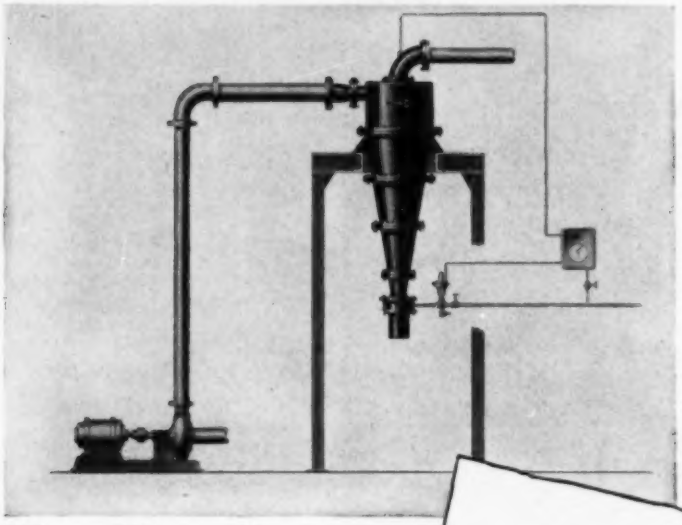

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#2	3.5	22.1	69.8	5.8	93.88	97.07	36.9
#3	6.0	13.3	67.2	4.4	97.23	88.07	25.5
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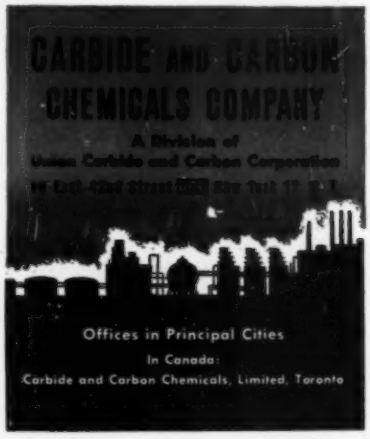
Freezing Point	—39°C.
Solubility in Water at 20°C	complete
Absolute Viscosity at 20°C	7.1 cps.
Flash Point (Cleveland open cup)	215°F.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OPINION AND COMMENT

REDESIGNING LIVES

Engineers, old, young, and in all stages of professional competency, have heard the plea about "doing something for the community," "getting into political life," "applying engineering thinking to world problems," etc., etc., etc., and etc. Titles may have been different, but the topic and the telling have been uniformly similar.

Though the challenge for engineers to help in the problems of community life is valid, and we are convinced that many have responded, the evidence of cooperation on the part of engineers is lacking. Personal observation convinces us that as a group, engineers not only have much to offer to the political and social life of the United States, but do participate as frequently in their own way, as the lawyer, doctor, and clergyman.

If the headlines feature other professions, it is to be remembered that the public is more apt to be interested in the parts played by other professions. However, engineers do help, and occasionally we come across examples of cooperation in everyday problems. A pleasant conversation at the Kansas City meeting with a young chemical engineer gave excellent proof of one way that service can be rendered by our profession.

This particular aid concerns the rehabilitation of criminals in a large state penitentiary. The engineer in question is giving five nights a week to teaching mathematics to a group of prisoners, all of whom asked for such help. The schedule calls for sessions of ten-weeks' length interspersed with three-week lulls. With enthusiasm the engineer reports that such work is the most stimulating he has ever done, and that once he has proved to his pupils that he is really interested in them, they respond by working to the best of their abilities.

Further, he has no discipline problems, for the prisoners have their own methods of discouraging unruly fellows. Such attention to the course stems not through any emotion of loyalty toward the instructor, but is based on the feeling that here at last is a chance to learn something useful, and possibly a chance for a new life—when.

Speaking about his work, our friend said that the problem as he sees it is to prove to the men that there are tasks, jobs, work, etc., that can be as satisfying to them as being criminals. He has to prove to each class of men that mathematics is worth while, that its honest application to engineering and other problems gives as much satisfaction as a well-planned criminal "big-job."

The whole theory of rehabilitation, according to our engineering friend is to understand that criminals have the same worries as other people, that they have similar skills, and they too need and cherish the satisfaction of a job well done. The one thing that seems to bind all these men together, the one thing that they have in common, is the feeling that there is no one who actually cares what happens to them or what has happened to them. The interest on the part of an engineer in their well-being is morale-building, and proof that people and society will help.

After demonstrating to a class the disadvantages inherent in gambling via probability, and proving by mathematics, facts that have never been quite apparent to them, the universal reaction is—"Why waste your time on us? With your intelligence you could be a wonderful 'square John.'" A "square John" in their parlance is a confidence man and this is one of the highest compliments they can pay.

The curriculum taught is, at present, on a high school level, or above, and one of the great compensations the engineer has obtained from this work is seeing one of his "graduates" recently place himself as an engineering trainee in the employ of one of our large machine companies. We respect the young man who is doing this work, and regret that we must keep him anonymous.

But here is an example, heart-warming, of an engineer serving his age in the best tradition. He is involved in the larger designs of life, in the big work of helping men in their own reconstruction and rehabilitation.

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MANUFACTURERS AND FABRICATORS OF CORROSION RESISTANT MATERIALS AND EQUIPMENT SINCE 1865

CHEMICAL PLANT OPERATIONS AND THE WEATHER

Indoor versus outdoor construction is a debate that is probably unique to the process industries, one that chemical engineers have brought on themselves by their talent for designing continuous operations which require a minimum of work supervision. Beginning here is a series of four articles on the advantages, disadvantages and economies on the construction of outdoor plants.

W. H. WILLIAMS
Dow Chemical Company
Midland, Michigan

THE Dow Chemical Co. has installations manufacturing similar types of chemicals in Michigan, on the Gulf Coast in Texas, in California, and in Ontario, Canada. These installations are as diverse as to housing as they are in other respects, and weather, or the lack of it, appears to be the least influential factor. There is more of a correlation between housing and the age of the installation, than between housing and the climate.

Where formerly almost all operations were housed, now the company constructs a building to reduce operating and maintenance hazards for personnel, equipment or process materials. The opinion of the operating supervisors of the weight of these factors for various processes and materials in relation to the weather of the locality is a major variable.

All of the above-mentioned varying, and frequently conflicting, factors must be considered in determining whether housing for any given installation should be complete, partial, or nonexistent.

In all the company's unhoused operations, clothing is furnished for protection against rain; and in Michigan, during winter, woolen clothing is supplied when necessary. There has been less absence from sickness in these plants than in most housed operations. It is further found that such operations work well in the coldest weather, if carefully designed and maintained to prevent freeze-ups, and 98 per cent of time on stream is readily obtained.

Advantages of Outdoor Plants

Strangely enough, one of the main advantages of the well-designed unhoused unit is its ease of maintenance. In Michigan, the maintenance is planned so that seldom is a major repair operation necessary in January and February, when temperatures below 20° F. can be expected in daylight.

The equipment is designed and placed in the unhoused plants so that it is capable of being replaced as units. A complete pump with its motor or a small fractionating column is disconnected and hauled to the shops for dismantling and repair. There, the work can be done more efficiently, and no operating hazard is created.

Spacing is such that mobile cranes can remove chlorinators, calandrias, condensers, columns or column sections, so that a minimum of manual labor is required to connect and disconnect. This reduces exposure of men to the weather, downtime and actual maintenance cost. The men are exposed to a minimum of toxic fumes, since local concentrations can be blown away by portable fans. Ventilation systems, which are usually ineffective during repair operations, and difficult to install and expensive to maintain are eliminated. The reduction of fire hazard is particularly important during the installation of additional units and major maintenance jobs.

Design Troubles

The most troublesome factor to be considered in the design of unhoused process equipment is the prevention of the freezing of materials in pipe lines. In Dow practice each project is surveyed for the limiting factors to deter-

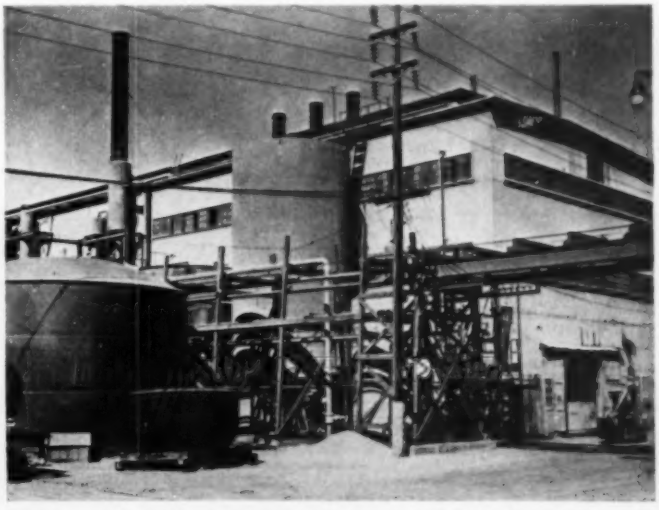


Fig. 1. Caustic soda evaporator house at Pittsburg, Calif.

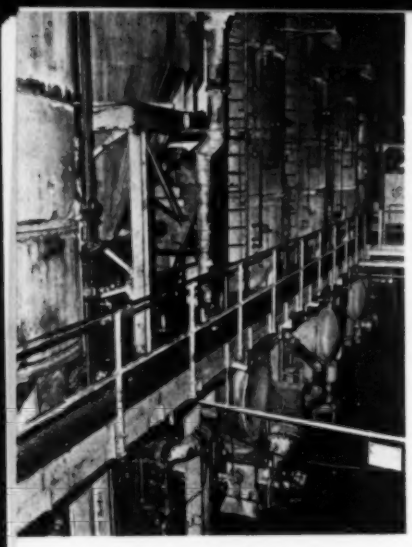


Fig. 2. Caustic soda evaporators at Pittsburg.

mine the proper protection for the most severe conditions. This may be an exceptional condition, such as when the operation is shut down and there is no flow, or when a leaking condenser contributes droplets of water to a nonfreezing liquid like chlorobenzene. Unless some means is provided to take care of these circumstances, such as to insure removal of the water or heating the pipe line to above freezing temperature, the water will freeze and build up until the pipe line is plugged. A successful engineering job will take care of all contingencies as well as regular operating conditions; and the proof of successful engineering will be demonstrated when we have no freeze-ups. In Michigan the company occasionally experiences a 30-mile an hour breeze at 20° below zero F. or minus 29° C.

Figure 1 gives an example of the type of construction that was prevalent during World War I. This is one of Dow's oldest installations, the Great Western division's caustic soda evaporator house at Pittsburg, Calif. At Midland, operations on caustic soda parallel this development in many ways and also are housed. Figure 2 is a view of the equipment in the evaporator house. It was not crowded when it was originally designed, but the first cost of incremental expansion is less when spaces between existing equipment are filled up. Reasons for this are: the difficulty of coordinating the location of the building for the expansion as well as the cost of the additional building, the cost of the duplication of service facilities and added labor costs, even though the original crew is not too busy when the new equipment is not adjacent to the original installation.

Such savings are questionable, however, when one considers lost production during repair operations, as well as added cost for repairs in close quarters.

When Dow started the caustic soda process on the Gulf Coast in 1940, the majority of it was open to the weather, as shown in Figure 3. The original evaporators were housed, however. When it came to expansion, although the building simply could have been extended, it was decided to install evaporators and barometric condensers out-of-doors (Fig. 4). The building houses personnel, filters, and other critical types of equipment. The packaging operation also is housed.

The crane rails above the evaporators aid in maintenance. Similar unprotected crane installations have been operating in Michigan since 1926, and while we have some trouble in wet and icy weather from the electrical contacts, it has never been of sufficient nuisance to justify housing.

In processing 70 to 75% caustic soda as a molten liquid at 80° C. (Fig. 5), the caustic is pumped through traced- and covered-pipe lines. A good insulation job, effectively maintained, is absolutely necessary, even on the Gulf Coast.

Materials melting below 100° C. can readily be handled in steam-traced and insulated-pipe lines heated with 150 lb./sq.in. gage steam. The tracer line should be designed so that it will transfer enough heat to the air bath surrounding the pipe so that the pipe wall temperature will always be above the freezing point of the liquid in the pipe.

The tracer should be of such diameter and length that it has steam throughout its full length and not condensate only at the far end. Obviously, if the line freezes, one has a major job thawing it out, and much of the tracing will probably be damaged as well as the insulating material. It is false economy to underestimate the heat requirements to keep the line from freezing. Installation and maintenance of the insulation must be perfect to approach the handbook figure of efficiency. The required surface of the tracer line indicated by heat loss calculations is doubled by doubling the diameter, and assumption is that steam use is double the calculated heat requirement when determining the length of the tracer line between feed point and the steam trap. A tracer line is usually equipped, near its discharge end, with a thermal air valve which furnishes a tell-tale by blowing steam into the air if the trap ceases to work and the tracer cools. This tell-tale wastes some steam, but saves frozen lines. In Michigan, the traps on the tracer lines are grouped where possible and enclosed in a cabinet, so that if one fails the others will keep it from freezing until it can be serviced. This grouping of the steam traps is advantageous from the standpoint of servicing, since there is less chance for neglect than in the case of isolated traps.

Pipe lines carrying noncorrosive materials are sometimes installed in a chase

Fig. 3. Caustic soda operations at Freeport, Tex.

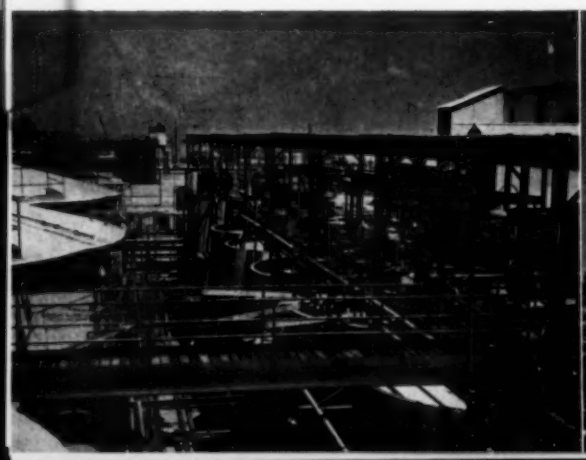
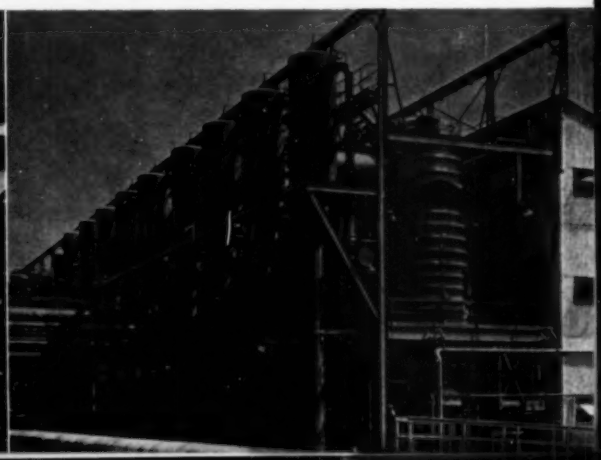


Fig. 4. Caustic soda evaporators at Freeport, Tex.



or otherwise boxed together to utilize the heat loss from the warm lines to protect the others. Such a procedure is applicable where there is little maintenance, as the lines are difficult to repair in close quarters. When corrosive materials are in pipe lines, damage to other lines will result from a leak, and a chase is no asset.

Handling Inflammables

Special precautions are necessary for processing materials classified as Class I Inflammable Hazards by the National Board of Fire Underwriters. Figure 6 is a view of the Dow (Midland) plant for the production of mono- and dichlorobenzene. This plant was started in the late Twenties and expanded through the Thirties and Forties. The wide spacing of the various units is for safety, fire protection and ease of maintenance. The control room and the headquarters for the operating personnel for the four batch stills and the three continuous stills separating benzene, mono- and dichlorobenzene are seen in the right foreground as a brick building behind the four tanks. The third continuous still is not shown.

Process benzene storage is shown in Figure 7. Since benzene freezes at 5° C., it is pumped through traced and insulated pipe lines (seen above the tanks). The traps for the tracer lines are in the cabinet in the right foreground. The tanks are covered with a minimum of two feet of earth to prevent freezing, reduce the evaporation losses and the fire hazard.

The benzene is chlorinated in the installation shown in Figure 8. This is a continuous operation, and 98 per cent of the time on stream is experienced for chlorinators in spite of corrosion and weather. The cabinet enclosing some steam traps for this unit is in the center foreground. At the left are shown hydrogen chloride and chlorine pipe lines for the 300 tons of chlorine a day used here. The spacing is such that a mobile crane can service this unit effectively. Headquarters for the personnel in this area and the control room are not shown, but are at the ground level, just to the right of the

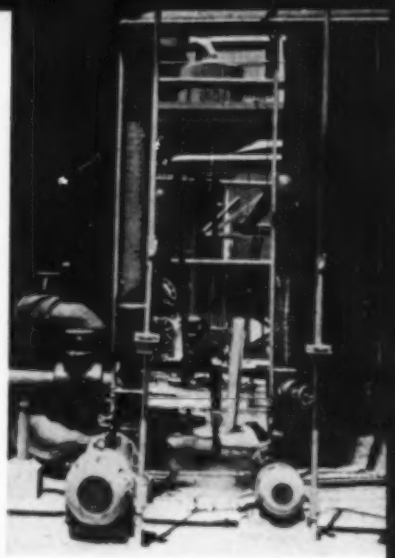


Fig. 5. Equipment for 75% caustic soda processing. ►

▼ Fig. 6. Mono- and dichlorobenzene processing at Midland.

Fig. 7. Earth covered benzene storage at Midland. ▼

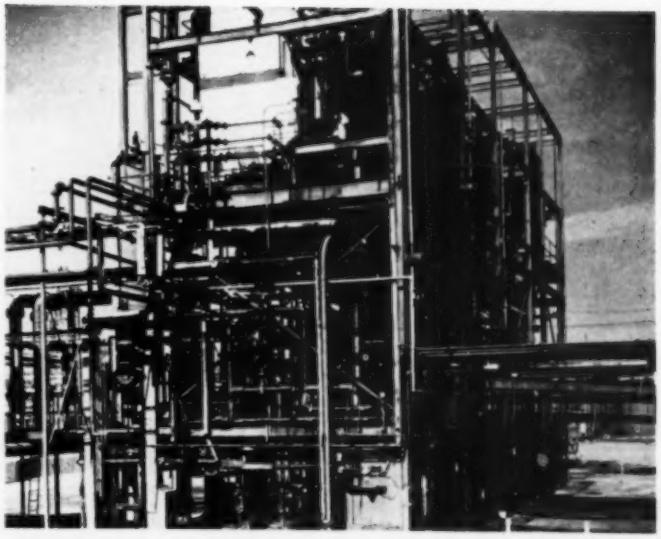


Fig. 8. Chlorinators for mono- and dichlorobenzene at Midland. ►

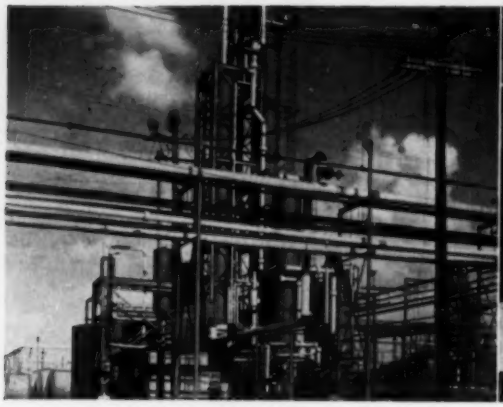


Fig. 9. Continuous still for refining monochlorobenzene at Midland.

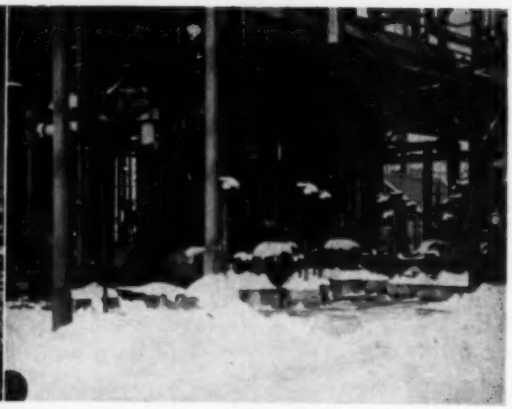


Fig. 10. Pumps servicing still refining monochlorobenzene at Midland.

pictured area. The chase leading from the chlorinator structure across the cleared space and into the control room encloses the instrument lines.

One of the three continuous stills separating benzene, mono- and dichlorobenzene is seen in Figure 9. The building houses the electric starters, water strainers and control instruments for this one unit. Key readings are transmitted to the headquarters control house noted in Figure 6.

The other side of this still, a close-up of the pumps servicing it, is shown in Figure 10. Lights in the headquarters control house indicate whether the pumps are operating.

A phenol still in Midland is shown in Figure 11. Here water is separated from phenol, and phenol (M.P. 40.8° C.) from orthophenylphenol melting at 56° C., and paraphenylphenol melting at 165° C. Most of these pipe lines are traced, but those carrying paraphenylphenol are jacketed with 150 lb./sq.in. gage steam. Dowtherm *E* and *A* are also used for heating jacketed pipe lines, and the latter is used to process molten caustic soda up to 400° C. The building houses pumps, filters, instruments, laboratory, locker room, and other personnel facilities. Process and instrument lines for another part of the phenol-processing operations are carried on the communications bridge in the left foreground. Bone-dry air for exposed instrument lines is essential in Michigan. Calcium chloride dryers for small operations are used, but for continuous large volumes of air with a dewpoint below −20° C., a regenerative type of dryer is used.

Another example of construction frequently used for out-of-doors installations where periodic personnel attention to the equipment at various levels is required is the ethyl benzene plant at Midland. Earth-covered benzene storage tanks are used and Figure 12, a close view of the operating galleries, shows equipment in detail.

Styrene operations furnish a comparison of out-of-doors construction in the North and the South. Figure 13 shows the Midland (Mich.) plant and Figure 14 the styrene operations in Velasco, Tex., on the Gulf Coast. At Velasco the benzene tanks are in the mounds beside the stills in the background. While freezing is not much of a factor, the other advantages are well worth the extra cost of this type of storage. The tanks are above grade because of the high water table in this area.

There are four independent trains of crackers and stills similar to the com-

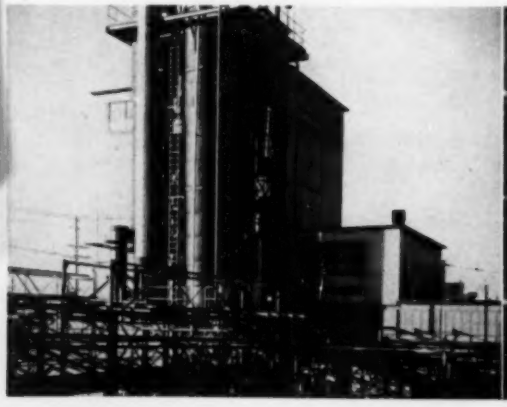


Fig. 11. Phenol distillation unit at Midland.

Fig. 12. Operating galleries of ethyl benzene plant at Midland.

plete unit pictured in the center. These units are operated by crews located in the brick control houses for each group.

The Dow ethylene glycol plant at Freeport, Tex., is shown in Figure 15, and the chlorinated methane operation in Figure 16. One of the biggest advantages of out-of-doors installations is indicated in these views which show the multitude of pipes that must be accommodated—there is always room for them out of doors. A close-up of the gravity control station for recovering hydrochloric acid from chlorinated methane is shown in Figure 17.

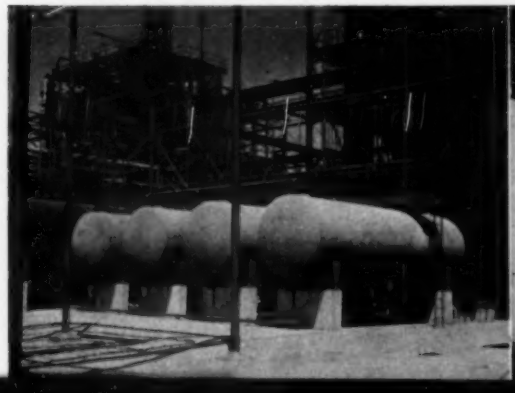
Another chlorinated methane operation at Pittsburg, Calif., antedates the Texas operation, and is shown in Figure 18. This is typical of Dow engineering for corrosive and hazardous operations, either toxic or fire. Methyl chloride, methylene chloride, chloroform, carbon tetrachloride, perchloroethylene and hydrochloric acid are all made in this plant. Note the separation of the personnel facilities and the spacing of the

Fig. 13. Styrene operations in Midland.

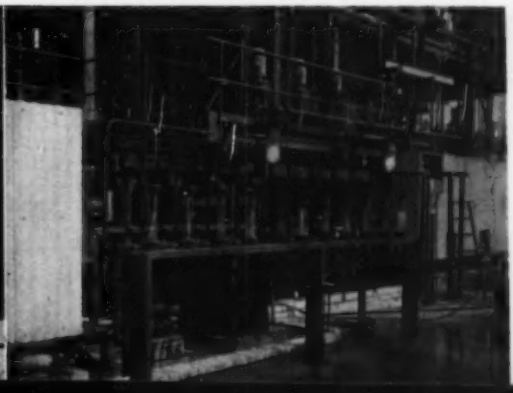
Fig. 14. Styrene operations in Velasco, Tex.

Fig. 15. Ethylene glycol plant at Freeport.

▼ Fig. 16. Chlorination of methane at Freeport.



▼ Fig. 17. Hydrochloric acid control station at Freeport.



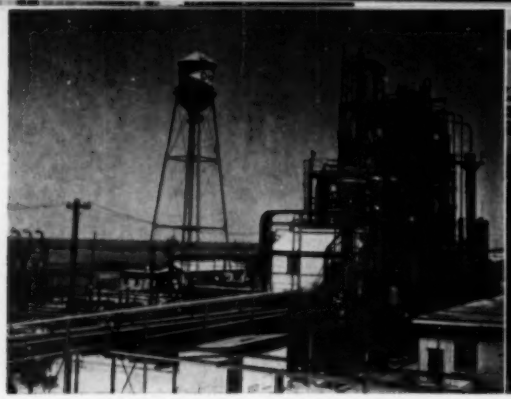


Fig. 18. Chlorination of methane at Pittsburg.

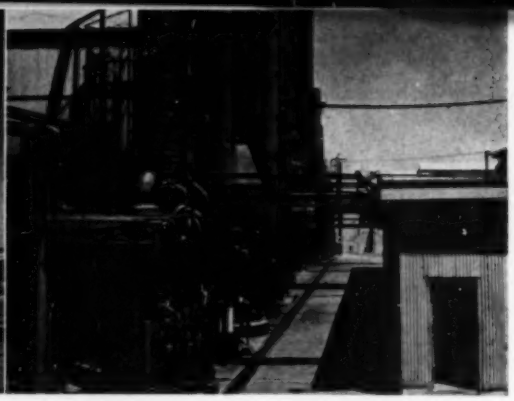


Fig. 19. Main operating alley at Pittsburg chlorinated methane plant.

equipment to minimize the exposure to hazardous chemicals. The pumps and compressors are protected from rain by the floor above each level, which is tightly fitted checker plate. The building on the second level houses electric starters and switch gear.

The main operating alley is shown in Figure 19. The indicating instruments are shown in front of the columns on the left, and can be observed from the windows of the control room on the right. This building also houses the recording instruments, repair shop and personnel facilities.

Fig. 20. War-built latex plant.

An explosion in Midland last spring blew out the end of a latex plant. Figure 20 shows an end of the building before the explosion. This building was built during the war and represents what was obtainable, not what the company wanted for such an operation.

The reactors were installed in the end of the building with a fire wall separating them from the rest of the building. The fans in the ventilation system were calculated to change the room air every six minutes, and all the electrical equipment was classified explosion-proof.

Only minimal quantities of butadiene were present in the reactors, since the feed rate balanced the reaction rate. The explosion was caused by a leak from a safety relief line into the room. The ignition source has not been discovered, but some evidence indicates static from the escaping gas may have furnished the spark.

The end of the building was rebuilt with the equipment open to the weather (See Fig. 21). This is a batch process which requires visual inspection of the operation as well as frequent sampling, cleaning and inspection of the reactors.

Men and instruments are protected from the weather between such operations by the enclosures on the second and third levels. (Note the escape tube.) A view from the other side showing more of the equipment is shown in Figure 22.

Experience at Dow indicates that fear of maintenance problems in bad weather is the main reason that operating supervisors require selling on the idea of unhoused plants. The company has converted several major operations from housed to unhoused in the last 15 years, and the operating superintendents are all satisfied with the change.

There are headaches and wet backs with unhoused operations; they are far from perfect, and while some new problems develop, the reduction of the maintenance, fire and health hazards in the unhoused units outweigh the new difficulties. This is true even in Michigan, where we say we have nine months of winter and three months of poor sleighing.

Acknowledgment

I wish to express my appreciation to The Dow Chemical Co. for permission to publish this material and to the Dow men who have contributed their comments and criticism.

(Presented at Minneapolis (Minn.) Meeting.)

▼ Fig. 21. Rebuilt latex operation at Midland.

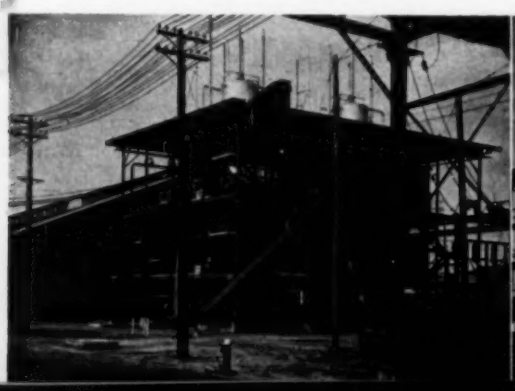
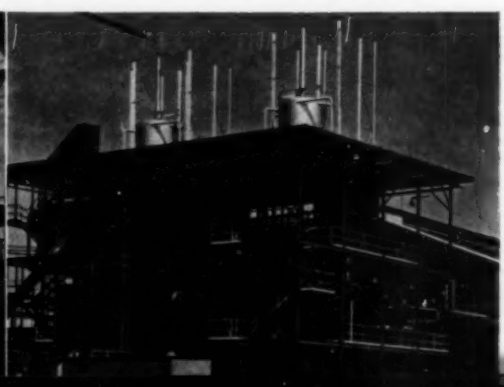


Fig. 22. Latex plant at Midland.



ISOMERIZATION AND HYDROGENATION REACTIONS IN A RECTIFICATION COLUMN

LLOYD BERG, P. R. HIPPELY, and W. S. REVEAL

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Work of an exploratory nature has been done using apparatus which allows catalytic reactions to be carried out concurrent with fractionation. Only reactions in which the product is lower boiling than any of the reactants have been carried out.

The following reactions were studied: isomerization of paraffins, using Isocel, an aluminum chloride impregnated activated bauxite; isomerization of naphthenes, also using Isocel; hydrogenation of di-isobutylene, mesityl oxide and nitropropane, using a hydrogenation catalyst. All reactions took place at the boiling points of the reagents and were run under atmospheric pressure (average: 635 mm.).

FREQUENTLY in catalytic reactions the desired product is only a small fraction of the equilibrium mixture produced at reaction temperature. The laborious procedure of batchwise separation, involving repeated transfer of the product to the separator and recycle of the undesirable major fraction to the reactor, discourages development of many otherwise attractive processes, especially when the equilibrium amount of the desired product is small. The problem could be simplified by continuously upsetting the equilibrium by the removal of the desired product as formed and re-establishing the equilibrium of the remainder by means of the catalyst. In many instances separation of the product can best be done by rectification, and frequently the catalyst is of a physical shape not wholly unacceptable as a rectification column packing. Hence, a scheme was devised whereby a portion of the packing of a rectification column is substituted by a catalyst of a size and shape resembling column packing. Reaction takes place in the catalyst section and equilibrium between reactants and products is approached. The remainder of the column removes the lower boiling portion of the product, while the rest of the product, now no longer of equilibrium composition, is returned to the catalytic reaction section as reflux.

The problem was to investigate a number of contact catalytic reactions wherein the product was lower boiling than any of the reactants and to develop a suitable apparatus for carrying out such reactions so as to remove the product as formed. Reactions which take place at approximately the boiling points of the reagents would require the least elaborate equipment, and from reactions of this kind typical examples were chosen for study.

A search of the literature revealed that isomerization of paraffins had been accomplished, using similar methods, by several investigators. Robertson (*6*) used a 5-ft., 30-plate, carborundum packed distilling column in the still-pot of which were placed *n*-heptane and 10 wt. % aluminum chloride. The product boiling below *n*-heptane was continuously removed. Similarly, *n*-butane was isomerized to isobutane in 85% yield using 25 wt. % aluminum chloride and 40 lb./sq.in. hydrogen chloride gas circulating in the system. Robertson's system necessitates batch operation in which the catalyst must be changed with each new charge. Sweeney (*8*) isomerized paraffins using an aluminum chloride impregnated catalyst as column packing. The central portion of a distilling column contained the catalyst, and above and below it was space for fractionation. The aluminum chloride could be used in slurry form and allowed to flow down a series of baffle plates and recycled. Ross and Pezzaglia (*7*) simultaneously isomerized and separated cycloparaffins from acyclic paraffins using a liquid hydrocarbon aluminum chloride complex run countercurrent to the vapor stream in a distilling column. The column was kept at isomerization temperature and hydrogen chloride gas introduced near the bottom. Upham (*10*) isomerized paraffins using an aluminum chloride sludge activated with hydrogen chloride and simultaneously alkylated the isomerized product with low boiling olefins. The product, a stabilized, liquid, branched-chain, saturated hydrocarbon, was withdrawn from the stripping section of a distilling column in which the reactions took place. Loy (*5*) isomerized hydrocarbons in a distilling column using aluminum chloride dissolved in liquid sulfur dioxide. A catalytic hydrogenation of azines was carried out simultaneously with distillation by Beregi (*1*) who noted that by displacing the equilibrium by distillation of primary amine in proportion to its formation, the production of the alzadines can be made to favor, exclusively, the primary amines.

The purpose of the present work was to investigate a number of reactions which might profitably be carried out concurrent with fractionation, the characteristic of each reaction being that the desired product is lower boiling than any of the reactants. Thus could be combined into one operation and one piece of equipment a process usually involving two separate and consecutive operations. No attempt was made to obtain exhaustive data on conditions and yields, or ways and means of improving yields. Sufficient data were not taken on each reaction to validate positive conclusions as to mechanism, reaction rate, optimum conditions, or the effects of changing the process variables.

Materials and Equipment

The apparatus used consisted mainly of a distilling column to which could be attached a reaction chamber containing catalyst. The column used was a 4-ft. Pyrex tube of 1-in. I.D., packed with either ⅛-in. stainless steel helices (Fenske) or ⅛-in. glass helices. The column was double-jacketed to minimize heat transfer to the surroundings, the inner jacket being wound with Nichrome wire as a heating element. A Variac or Powerstat was used to control the temperature of the jacket. The column calibrated about 30 theoretical plates with a test mixture of toluene-methylcyclohexane at total reflux. The bottom of the column ended in a ground-glass 35/25 spherical fitting to which the reactor was attached by means of the spherical joint and a *C*-clamp.

The reactor was a 10-in. length of 48 mm. Pyrex tubing fitted with ground-glass,

TABLE 1.—RESULTS: ISOMERIZATION

Run Number	1 & 1A	2	10	3	5	6
Charge:						
Reagent	n-Pentane	n-Pentane	n-Pentane	n-Hexane	n-Hexane	n-Hexane
Weight, g.	203.6	234.9	179.9	216.8	193.3	234.4
B.P., ° C. (635 mm.)	30.9	30.9	30.9	69.2	69.2	69.2
Refractive Index	1.3577	1.3577	1.3577	1.3760	1.3760	1.3760
Catalyst:[1]						
Weight, g.	230.9	266.9	220	From 2	270.4	From 5
Product:						
Total weight, g.	67.8	56.7	66.3	18.3	46.8	38.8
Boiling range, ° C.	28.7–30	24.5–30.2	<24.5[3]	54.8–60	45.6–54.8	59.2–60.4
Refractive index range	1.3551–1.3566	1.3538–1.3556	1.3540	1.3630–1.3732	1.3694–1.3713	1.3740
Per cent yield	33.3	24.1	36.9	8.5	24.3	16.6

Run Number	8	9	11	12	13
Charge:					
Reagent	n-Hexane	n-Hexane	Cyclohexane	Cyclohexane	Methyl-Cyclohexane
Weight, g.	226.5	100 + R[2]	295.7	100 + R[2]	214.6
B.P., ° C. (635 mm.)	69.2	69.2	74.8	74.8	99.7
Refractive index	1.3750	1.3750	1.4262	1.4262	1.4230
Catalyst:[1]					
Weight, g.	268.4	From 8	257.8	From 11	269
Product:					
Total weight, g.	64.3	29.7	142.3	123.5	89.1
Boiling range, ° C.	43.6–58	56.8–60.2	63.8–66	64.8–66.2	80.8–88
Refractive index range	1.3648–1.3735	1.3734–1.3742	1.4077–1.4101	1.4101–1.4106	1.3986–1.4130
Per cent yield	28.4	28.8[4]	48.2	67.2[4]	41.5

[1] Catalyst is 6-14-mesh Isocel except run 10 which is 4-8-mesh Isocel.
[2] Collected as dry-ice condensate.
[3] Residue from preceding run plus 100 g. fresh reagent.
[4] Total yield including previous run.

spherical fittings. The catalyst was supported in this reactor by means of a 20-mesh, stainless steel screen, bent in the shape of a cone and forced into the bottom of the reactor. The reactor was wound with a layer of asbestos tape, a spiral heating winding of Nichrome wire, and another layer of tape. A temperature of about 300° C. was obtainable in the reactor at maximum amperage (5 amp.) and voltage (70 v.). A relative temperature reading in the reactor was obtained by placing a mercury thermometer between the asbestos tape windings and the reactor. The reactor was easily removed for catalyst change or inspection, and air could be excluded from the interior of the chamber merely by inserting rubber stoppers in both ends of the reactor as soon as it was removed from the column.

The still pot was attached to the spherical joint at the bottom of the reactor. The pot was heated by an electric coil ceramic stove constructed to fit round-bottom flasks. The heat applied to the stove was regulated with a 110-v. Variac.

Isomerization. For the isomerizations a 1-l. Pyrex round-bottom flask with a spherical fitting served as a still pot. The condenser was a simple cold-finger reflux condenser, the reflux being adjusted by means of a stopcock in the take-off line. The distillate was collected in a 50 cc. side-arm Erlenmeyer flask, the side-arm of which was connected to a dry-ice trap.

Hydrogenation. A 1-l. Pyrex round-bottom flask with a spherical fitting and a sampling tube was used as a still pot for hydrogenation. The sampling tube extended inside nearly to the bottom of the flask so that hydrogen could be bubbled through the liquid in the flask. The distillate receiver was a 10-in. side-arm test tube with a stopcock at the bottom. Excess hydrogen and uncondensed vapors were removed via the side-arm to a dry-ice trap and then to a wet test meter. By means of the stopcock in the receiver, samples could be taken without stopping the hydrogen flow or allowing hydrogen to escape into the room. Hydrogen from a cylinder at 2000 lb./sq.in. was reduced to a pressure of 4 or 5 lb./sq.in. by a reducing valve and entered the still pot via a needle valve and rubber tubing.

Procedure

In general, experimental procedure was as follows: A weighed amount of the reacting liquid was charged cold to the still pot. The reactor, partially filled with a weighed amount of the desired catalyst, was clamped to the column and still pot, and care was taken to keep it vertical to prevent channeling. When possible, the column was first flooded and the pot heat then adjusted to a value just below that which caused flooding. The system was then run at total reflux until equilibrium, as indicated by a constant overhead temperature, was established, requiring from one to three hours. Distillate was collected at a rate dependent upon the change in overhead temperature. An effort was made to keep the temperature range of each distillate sample as small as possible; therefore, when the temperature tended to rise rapidly, the individual samples were small and the reflux ratio high. The weight and refractive index of each sample were recorded.

No attempt was made to isolate pure compounds from any of the samples, and no chemical or physical treatment other than washing or drying was accorded any of the products. The reaction was continued until the overhead temperature and/or refractive index indicated that no further product of value was being obtained. The system was then shut down, the catalyst chamber removed and closed off to protect it from air, and the residue in the still pot weighed, and, in some cases, its refractive index taken. If the results of the run were positive, an attempt was made to reproduce them in a subsequent run or runs.

Isomerization. The first isomerization runs were carried out with the reactor not externally heated. Some difficulty was experienced in obtaining sufficient throughput in the column without causing the reactor to flood over the catalyst bed. The catalyst used was 6-14 mesh Isocel, and its irregular shape caused it to pack to some extent, making it difficult for the reflux to flow down through it. Dispersing the catalyst by mixing it with ½-in. Berl saddles or ⅛-in. helices, or by layering these materials alternately, was of no help, nor did filling the 4-in. free space at the top of the catalyst bed with Berl saddles improve operation. When the reactor was wound with a Nichrome heating element and heated to approximately the boiling point of the material in the still pot, throughput was more satisfactory, although flooding was still experienced at temperatures below that which would have given optimum reflux. Even at reflux ratios as low as 5:1, the rate of take-off was comparatively small. A control run using ⅛-in. pellets of alumina, which has no catalytic action at the low temperature used, showed a throughput superior to that obtainable with the Isocel. Unfortunately, Isocel catalyst is not available at present in pellet form. The 4-8 mesh size showed characteristics superior to the 6-14 mesh catalyst, but not as good as the pellets. Since aluminum chloride is deliquescent, air was excluded from it as much as possible by closing off the ends of the reactor with rubber stoppers when not in use. A portion of catalyst was used until it no longer caused isomerization to take place.

It was necessary to run the paraffin isomerizations at high reflux ratios so that the product would not be taken off faster than formed. Normal pentane isomerized rapidly enough for a reflux ratio of about 30:1, normal hexane required about 40:1, and normal heptane and normal octane isomerized too slowly at their boiling temperatures to enable isomerized product to

be taken off at any reasonable reflux ratio. If the temperature appeared to be rising too rapidly, it was possible to cause it to decrease again by allowing the system to run at total reflux for a time; that is, equilibrium was allowed to re-establish itself while no product was being taken off. When the temperature again reached a constant value, take-off was recommenced at a higher reflux ratio.

The naphthenes isomerized comparatively readily and pure product could be obtained with a reflux ratio of 20:1.

Hydrogenation. The procedure for hydrogenation involved bubbling hydrogen through the material in the still pot, otherwise it was the same as the isomerization procedure. In the first hydrogenation run an attempt was made to reduce di-isobutylene to iso-octane; the system was allowed to run at total reflux for an hour before passing in the hydrogen. The reactor heat was then turned on and hydrogen flow started. After several hours, no hydrogenation had taken place. It was found that the catalyst needed to be activated by passing hydrogen over it at 200-250° C. before beginning the boil-up. Activation was accomplished by bubbling hydrogen through the reagent in the still pot for an hour with no heat applied to the pot, but with the reactor heat on full. The reactor was allowed to cool to the boiling point of the reagent, and, with hydrogen still flowing into the system, the pot heat was turned on and the system run at total reflux until the temperature reached a constant value. The hydrogen delivery pressure was kept constant at about 4 lb./sq.in. and a relative rate of flow determined by observing the bubbles created by the gas passing through the reactant. Too high a gas rate would cause the column to flood in the condenser or at the top of the packing, but little difficulty was experienced in this respect and throughput was excellent. The considerable quantity of liquid entrained by the hydrogen was recovered by a dry-ice trap.

The hydrogenation catalyst used was active, and it was necessary to take precautions to prevent its prolonged contact with air. Air would spontaneously oxidize the catalyst, causing considerable heat to be given off. Catalyst so treated could not be reactivated at temperatures and pressures available to the investigators.

Discussion of Results

Isomerization. Isomerization results are summarized in Table 1. Reagents used were commercial compounds purified by fractionation to give the boiling points and refractive indices shown. Throughout the work "boiling point" refers to the overhead temperature in the distilling column, taken at the prevailing atmospheric pressure (average: 635 mm.). Data for all pure hydrocarbons are taken from Doss (*3*) and for pure organic compounds other than hydrocarbons from the Chemical Rubber Handbook (*4*).

In runs 3, 6, 9, and 12 the catalyst was that used in the preceding run. All other runs were made on fresh catalyst.

Included as "product" are all overhead materials having boiling points and refractive indices sufficiently different from those of the reagent to indicate isomerization has taken place, plus the contents of the dry-ice trap. In run 2 all the product was collected in the dry-ice trap, the overhead temperature during collection being less than 24.5° C. Per cent yield is simply the ratio of total product to weight charge, expressed as per cent. Run 9 was continued from run 8 by addition of 100 g. of fresh reagent to the residue in the still pot. The per cent yield shown for run 9 is the ratio of the total product from runs 8 and 9 to the total reagent weight charged to both runs. Similarly, run 12 shows a per cent yield which includes runs 11 and 12.

Normal pentane, the easiest to isomerize of the paraffins investigated, gave a product of boiling range 24.5-30.2° C. The boiling point of pure normal pentane is 31° C. and that of isopentane is 22.9° C. The refractive index of the product ranged from 1.3538 to 1.3566, while the refractive indices of normal and isopentane, respectively, are 1.3576 and 1.3539. Thus it appears that the product was a mixture of iso- and normal pentane. No neopentane was detectable.

Hexane isomerization, though somewhat slower than pentane, showed similar characteristics with the additional feature of noticeable catalyst deactivation. It was found that a given weight of Isocel kept in the reactor for several runs would produce a certain weight of neohexane isomer and no more, even if fresh normal hexane were charged. After this weight of neohexane was removed, a certain amount of isohexanes could be produced, and after these fractions had been removed, no further isomerization would take place. This cycle was fairly short, taking about two volumes charge per volume catalyst to "use up" the catalyst.

The product of the hexane isomerizations apparently contained all the hexane isomers, including neohexane. The refractive index range of the product was 1.3630 to 1.3842, while the refractive index of normal hexane is 1.3750 and of neohexane 1.3688. As in all of the reactions studied in this work, no attempt was made to isolate pure compounds from the products. However, an examination and comparison of the boiling points and refractive indices of the products and of the pure compounds that might be expected was usually sufficient to indicate to what extent and end the reaction had proceeded. The fact that the hexane isomerization product showed a refractive index range which extended below that of the lowest hexane isomer indicates that a certain amount of pentanes was also formed.

Normal heptane and normal octane isomerized too slowly to allow the product to be taken off as formed. At other than extremely high reflux ratios (50:1) the product taken off was pure normal compound.

The isomerization of cyclohexane was a rapid and comparatively easy process.

TABLE 2.—RESULTS: HYDROGENATION

Run Number	19	20	21	22	23–4
Charge:					
Reagent	Di-isobutylene	Mesityl Oxide	Di-isobutylene	Mesityl Oxide	Di-isobutylene
Weight, g.	240.3	358.7	200.0	420.9	165.3
B.P., ° C.	93.6	120	93.6	120	94.6
Refractive index	1.4095	1.4450	1.4095	1.4450	1.4095
Catalyst:[1]	Fresh	From 19	Act'd from 20	From 21	From 22
Product:					
Total weight	36.9[2]	124.0	121.9	276.1	79.5
Distillate No. 1,[3] g.	12.9	51.0	61.5	73.5	28.1
Refractive index		1.3597–1.3899	1.3910–1.3918	1.3597-1.3935	
Range	1.4090				1.3933
B.P., ° C.	91–91.4	50.3	65.8–86.6	50–106.4	88.2–91.2
Distillate No. 2, g.	10.	30.5	41.6	202.6	33.4
Refractive index			1.3918–1.3921	1.3951–1.3959	
Range	1.4090	1.3591			1.3924
B.P., ° C.	91.4–91.6	50	86.6–87.8	103.7–106	66.4–88.2
Distillate No. 3, g.	14	42.5	16.8		20.0
Refractive index		1.3624–1.3658	1.3929–1.3937		
Range	1.4090				1.3943
B.P., ° C.	91.6–94.4	50–70.5	87.8–88.2		88.2–88.5
Per cent yield	0[2]	34.7	61	64.2	48.1

[1] Catalyst in each case is 238.5 g. of U.O.P. hydrogenation catalyst.
[2] No hydrogenated product.
[3] Distillate No. 1 includes dry-ice condensate.

The product was almost entirely methylcyclopentane of high purity (refractive index range 1.4077-1.4106). The refractive index of pure methylcyclopentane is 1.4090. The yield was comparatively high, 67%, and the catalyst seemed to retain full activity after two volumes of cyclohexane had been charged per volume of catalyst.

A similarly easy isomerization was that of methylcyclohexane. The product, however, was so mixed that it was impossible to say definitely which isomer appeared in preponderance. The refractive index of the product ranged from 1.3988 to 1.4130, indicating 1,1- and 1,2-dimethylcyclopentane, but probably all the possible isomers are present to some degree.

Hydrogenation. Table 2 presents the hydrogenation data. The product was collected in three portions labelled distillate No. 1, 2, and 3, each distillate covering a small boiling point and refractive index range. When the boiling point changed or seemed about to change more rapidly, a new distillate sample was started. In run 22 the range was so small that the product was divided into only two large portions. The dry-ice condensate was added to distillate No. 1.

Run 19 shows no hydrogenation because the catalyst had not been activated. Run 20, also with unactivated catalyst, shows some hydrogenated product, but not so much and not nearly of as good purity as run 22 on the same reagent using catalyst which had been activated by passing hydrogen gas over it at about 250° C.

The hydrogenations proceeded readily to give products of a high degree of purity. Di-isobutylene was reduced in good yield to iso-octane (2,2,4-trimethylpentane) of high purity. The boiling range of the product was 85.8-88.2° C. and the refractive index range was 1.3910-1.3937, with the bulk of product in the 1.3910-1.3921 refractive index range. Corresponding values for pure iso-octane are 92° and 1.3914. It should be noted here that hydrogen passing through the column acted to reduce the overhead temperature three to six degrees. When the hydrogen flow was stopped, the overhead temperature rose immediately, even at total reflux. Applying a correction for this change brings the product analysis closely into line with pure iso-octane. The lower yield of runs 23-24 was caused by a partial oxidation of the catalyst. The great heat evolved by this spontaneous oxidation caused vapors to be produced in such rapid flow that the condenser and dry-ice trap could not condense them and some product was lost via the blow-down line. The anomalous behavior of the boiling point and refractive index in runs 23-24 is attributed to this catalyst oxidation, plus some contamination of the catalyst by mesityl oxide absorbed during the previous run.

Run 22 on mesityl oxide using properly prepared catalyst, yielded 64.2% of a product of boiling range 103.7-106.4° C. and refractive index range 1.3597 to 1.3959 (a small amount of the first overhead product appeared at 50° and 1.3597, probably due to reagent contamination). The great bulk of the product was in the range 1.3951-1.3959. The boiling range and refractive index of the expected hydrogenation product, methylisobutyl-ketone, and 108-112° and 1.3957, respectively. At the conclusion of run 22 the catalyst appeared partly deteriorated, and some time after the reactor had been removed from the still pot, spontaneous oxidation, producing considerable heat, occurred.

A run was made on 1-nitropropane to attempt reduction to propylamine. During this run, with no air in the system, the temperature of the reactor rose spontaneously to nearly 300° C. making it necessary to abandon the run. Examination of the catalyst showed that the portion nearest the still pot had crumbled to a black powder. This result, coupled with the outcome of the mesityl oxide run, led to the conclusion that this type of operation was not fitted for reduction of oxygenated compounds, particularly those possessing more than one oxygen atom per molecule. The manufacturer, however, states that the catalyst can be used for the reduction of mesityl oxide successfully if care is taken to exclude air from the catalyst region (9). He also states that nitroparaffins can be reduced using this catalyst if the temperature is kept at 20° C. and the reactants are liquid. Hydrogen pressure of 50 lb./sq.in. gage is recommended. The equipment as set up for this investigation had no provisions for pressurization or heat removal, therefore reduction of nitroparaffins was not studied further.

The effects of the hydrogen gas in the distilling column on the distillation characteristics present an interesting topic for further research. A large amount of liquid was collected in the cold trap during each run indicating that the hydrogen was entraining considerable liquid. The effects of this entrainment on column efficiency were not determined, although in the mesityl oxide run, number 22, 155 g. of product were taken off within a refractive index range of two in the fourth decimal place, indicating good separation. Entrainment was apparent if the hydrogen rate was too high, in which case the column would flood, beginning in the head and progressing downward. It is interesting to note that the entrained liquid collected by the dry-ice trap showed a refractive index approximately equal to that of the lowest boiling distillate in the range through which it was collected. It might be suspected that some of the higher boiling unsaturates would also be entrained and show up in the dry-ice condensate.

Conclusions

An examination of the results of the isomerization process reveals that, for the paraffins, equilibrium was not established fast enough to make rapid take-off possible. Thus, the particular value of this scheme would appear to be less for commercial production than as a research tool in the comparatively easy and inexpensive production of small quantities of pure compound.

The naphthenes, on the other hand, isomerize rapidly enough to merit development, should a market for one of the producible isomers arise.

The hydrogenation reactions present a field for further study and development. The ease with which iso-octane was obtained in high purity using this scheme indicates that the process would be attractive. Proper design of equipment would make this scheme applicable to the more difficult hydrogenations also. Thus, if provisions were made for pressurization and removal of the large excess of heat, nitroparaffins could be reduced to amines with comparative ease.

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DESIGN OF FIXED-BED CATALYTIC REACTORS

PART II

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Temperatures were measured at various catalyst bed depths and radial positions in a 2-in. I.D. reactor through which sulfur dioxide and air were passed. The catalyst consisted of ⅛-in. alumina pellets coated with 0.2% platinum. The reactor was cooled by boiling water in a surrounding jacket in order to induce large radial temperature gradients. The conversion of sulfur dioxide to sulfur trioxide was also determined. Data were obtained at four gas mass velocities ranging from 147 to 512 lb./(hr.)(sq.ft. of empty reactor area.)

A modified Grossman design method has been used for predicting temperatures and conversion in a fixed-bed reactor. Good agreement with the observed temperature and conversion data is obtained when this method is applied to the sulfur dioxide reaction, despite the fact that mass transfer in the radial direction is neglected.

The main experimental information necessary to use the modified Grossman method consists of (1), specific reaction rate data as a function of temperature, composition, and mass velocity, and (2), radial heat-transfer rates in packed beds. The reaction rate data, at present at least, must be determined separately for each reaction considered. However, there has been some progress made in correlating radial heat-transfer rates (in the form of effective thermal conductivities, K_e, or more appropriately, in the form of the group (K_e/cG)) with operating variables such as gas mass velocity and packing size.

IN a previous paper (*4*) an introductory study was made of the Grossman (*3*) method for predicting the conversion and temperature as a function of catalyst bed depth in a nonadiabatic reactor operated at a mass velocity of 350 lb./(hr.)(sq.ft.). The predicted and experimental results for temperature and conversion did not agree well, suggesting the need for additional data on effective thermal conductivities in packed beds and also for modification of the Grossman method itself.

Since the original paper, temperature and conversion data have been measured at three additional mass velocities (147, 244, and 512 lb./(hr.)(sq.ft.)) for the oxidation of sulfur dioxide. Also, more accurate effective thermal conductivity information (*1,2,5*) has become available. With the more extensive experimental data on hand for comparison purposes, the Grossman method has been re-examined and a modified design procedure proposed. Temperatures and conversions predicted with this modified design method are in reasonably good agreement with the observed results, even when radial temperature gradients of 200° C./(in.) are present.

Apparatus and Experimental Procedure

The equipment and methods employed to measure temperatures and conversion were essentially the same as those used in the earlier work and described in detail by Hall and Smith (*4*). The apparatus as a whole is shown in Figure 1. The stainless steel reactor, consisting of standard 2-in. pipe, was packed to bed depths approximating 0, 2, 4, 6, and 8 in. with ⅛-in., cylindrical, catalyst pellets. At each bed depth and mass velocity of gas, two types of measurements were made: (1) temperatures were determined with 11 to 14 chromel-alumel thermocouples placed across the diameter of the reactor, both within the catalyst pellets and in the adjacent gas stream, and (*2*) the mean conversion across the entire bed was ascertained from analyses of gas samples collected upstream and downstream from the reactor. The inlet gas composition was held constant at 6.45 mole % sulfur dioxide and 93.55% mole air.

The gas temperature entering the reactor was maintained at approximately 400° C. by means of a molten lead bath. The average absolute pressure was 790 mm. of Hg.

Experimental Data. The radial temperature distribution and conversion determined experimentally are given in Table 1 as a function of catalyst bed depth and gas mass velocity [lb./(hr.)(sq.ft. of empty reactor area)]. It is noted from this table that the actual bed depth corresponding to the nominal depth of 0 in. is 0.063 in. This distance corresponds to the position of the thermocouple junctions embedded halfway through pellets of catalyst in the lowest layer. The bed depths of 2, 4, 6, and 8 in. are also nominal values. Data in Table 1 indicate that, approximately at least, the temperature varies with radial position in a parabolic manner. This is illustrated in Figure 2 for a mass velocity of 244 lb./(hr.)(sq.ft.). After a bed depth of approximately 2 in., the temperatures at all radial positions begin to fall because of heat transfer to the boiling water jacket. Except for the lowest mass velocity, the maximum conversion is reached at a catalyst depth of 2 in. and does not change after that depth.

Data Required for Design Method

Any design method for predicting the conversion and temperatures in a nonadiabatic reactor requires two kinds of experimental data: (1) a knowledge of the spe-

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TABLE 1.—TEMPERATURE

Run No.	6B	2B	4B	6B	8B	6C	2C	4C
Gas mass velocity—lb./(hr.)(sq.ft.)	149	147	147	147	148	250	245	246
Actual catalyst bed depth—in.	0.063	2.25	4.25	5.94	7.98	0.063	2.25	4.25
Total mass of catalyst—g.	.....	120.7	243.0	346.7	462.9	.....	120.7	243.0
Mole % SO_2 in reactants (Flow meters)	6.46	6.51	6.55	6.47	6.44	6.35	6.48	6.47
Mole % SO_2 in reactants (Analysis)	.....	6.37	6.43	6.17	6.26	.....	6.41	6.29
Conversion—%	.....	15.9	16.5	17.2	20.7	.....	19.6	28.7
Reactor pressure—cm. of Hg.	77.1	77.3	77.1	77.1	77.4	76.7	76.9	77.3
Lead bath temperature—° C.	452.0	452.4	452.2	451.8	452.1	432.4	432.4	432.5
Reactor temperature—° C.								
Edge catalyst	274	180	109	140	...	314	232	217
Second catalyst	362	269	203	170	149	384	338	273
Third catalyst	410	318	225	....	151	401	410	336
Center catalyst	423	351	294	188	155	406	440	346
Fifth catalyst	...	...	...	172	153	...	...	....
Sixth catalyst	...	...	...	160	137	...	...	...
Seventh catalyst	...	...	...	131	116	...	...	...
Edge gas	346	178	145	131	121	255	232	185
Second gas	392	244	184	156	139	391	304	252
Third gas	418	322	217	175	153	405	408	310
Center gas	424	394	282	182	156	411	442	343
Fifth gas	404	353	...	....	153	402	440	353
Sixth gas	348	290	221	171	142	375	366	306
Seventh gas	340	220	170	147	125	373	274	229

cific reaction rate as a function of temperature, composition, and gas mass velocity (if diffusion is important), and (2) a knowledge of the radial transfer of heat within the catalyst bed, which is commonly interpreted in terms of an effective thermal conductivity, K_e.

Specific Reaction Rate. Rate data for the catalyst and conditions used in this investigation have been previously determined and presented (*8*) in the form of charts of reaction rate (lb. moles of sulfur dioxide converted per hour per pound of catalyst) vs. temperature, composition, and mass velocity. From these charts the specific reaction rates necessary for use in the design method could be readily selected.

Effective Thermal Conductivity. The equation relating the temperature and conversion to the catalyst depth in a fixed-bed reactor may be written

$$-\frac{\partial t}{\partial z}+\left(\frac{K_e}{cG}\right)\left(\frac{\partial^2 t}{\partial r^2}+\frac{1}{r}\frac{\partial t}{\partial r}\right)+\frac{a\beta q}{cG}\rightarrow 0 \qquad (1)$$

$$dx=\frac{a\beta(2\pi r dr)dz}{F} \qquad (2)$$

RADIAL LOCATION OF

Shown as Fraction

Actual catalyst bed depth (in.)	0.063
Edge catalyst	0.86
Second catalyst	0.61
Third catalyst	0.29
Center catalyst	0.08
Fifth catalyst	....
Sixth catalyst	....
Seventh catalyst	...
Edge gas	0.87
Second gas	0.58
Third gas	0.27
Center gas	0.12
Fifth gas	0.38
Sixth gas	0.70
Seventh gas	0.91

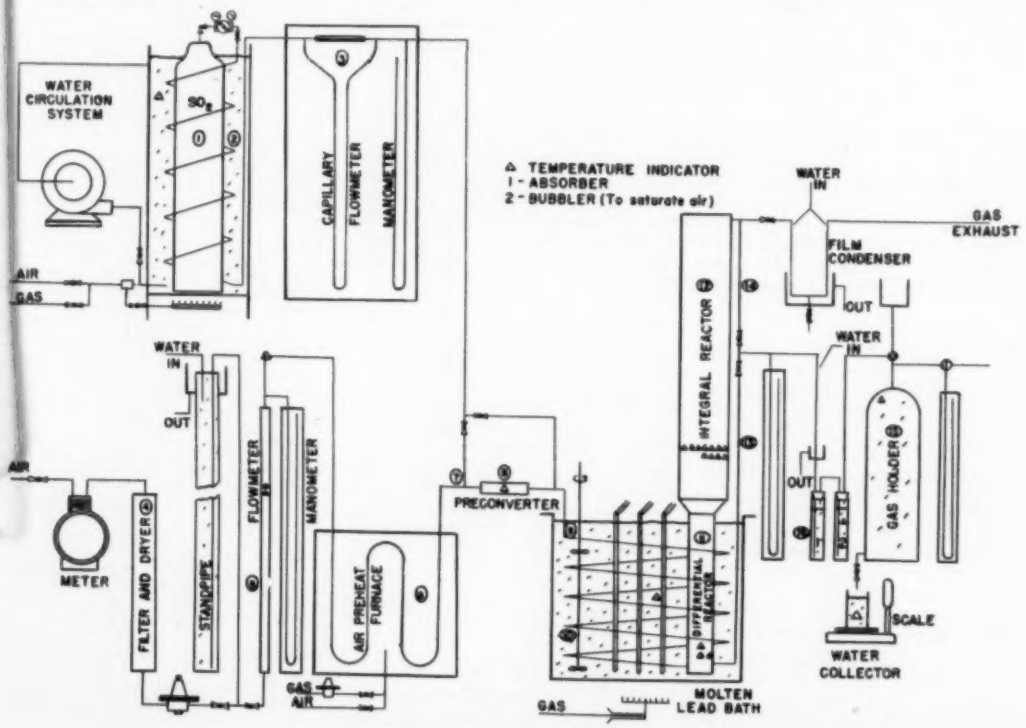

Fig. 1. Flowsheet of research apparatus.

AND CONVERSION DATA

6C	8C	0A	2A	4A	6A	8A	0D	2D	4D	6D	8D
245	245	348	353	352	356	353	503	512	510	514	514
5.94	7.98	0.063	2.25	4.25	5.94	7.98	0.063	2.25	4.25	5.94	7.98
346.7	462.9	.....	120.7	243.0	346.7	462.9	.....	120.7	243.0	346.7	462.9
6.47	6.45	5.89	6.46	6.48	6.40	6.43	6.53	6.38	6.49	6.44	6.45
6.46	6.41	.....	6.28	6.35	6.42	6.54	.....	6.44	6.40	6.33	6.41
23.3	29.0	.....	27.2	22.3	27.5	26.3	.....	18.3	19.2	17.7	16.8
76.7	76.7	77.6	77.5	77.6	77.7	77.6	81.0	81.0	80.9	81.3	81.3
427.4	426.4	414	438	414	413	413	409	409	409	409	409
180	147	313	246	236	205	162	341	263	260	208	170
237	181	382	371	299	279	208	391	386	348	287	220
....	206	385	430	....	....	244	396	444	388	....	261
265	214	398	464	379	314	256	397	468	396	312	275
241	211	....	....	....	280	255	....	....	....	296	271
219	176	....	....	....	265	207	....	....	....	269	220
164	137	....	....	....	193	153	....	....	....	188	158
165	144	317	224	182	194	162	355	236	186	196	166
210	180	364	339	262	250	213	390	351	278	252	222
252	213	397	424	333	306	256	395	436	353	312	273
265	218	402	472	376	324	262	400	453	404	328	282
....	210	398	468	....	....	....	398	476	....	....	264
242	186	379	399	338	283	220	388	412	358	291	227
196	152	290	311	242	221	171	317	324	256	239	175

THERMOCOUPLES IN REACTOR

of the Radius (r/r_o)

2.25	4.25	5.94	7.98
0.85	0.79	0.71	0.82
0.59	0.57	0.44	0.56
0.36	0.33	0.28	0.30
0.16	0.14	0.11	0.15
....	....	0.35	0.31
....	....	0.53	0.59
....	0.76	0.68	0.83
0.86	0.81	0.78	0.74
0.67	0.63	0.56	0.56
0.40	0.36	0.29	0.29
0.11	0.08	0.13	0.08
0.18	0.22	0.21	0.26
0.47	0.47	0.44	0.49
0.73	0.71	0.62	0.74

where x represents the conversion, and a the specific reaction rate. The other symbols are defined in the notation. These well-known equations are based upon several assumptions, the most important of which are equality of gas and catalyst temperatures, negligible heat transfer by conduction in the axial direction z, and negligible mass transfer in the radial direction r. The assumption of negligible mass transfer is questionable. However, the mechanisms by which mass can be transferred in the radial direction are limited to molecular and turbulent diffusion in the fluid phase, while heat transfer is possible by a number of other mechanisms.

It is apparent that the solution of Equations (1) and (2) for temperature and conversion requires a knowledge of the effective thermal conductivity in the radial direction, K_e, as well as the specific reaction rate a. Values of K_e have been determined by Hougen and Piret (5), Coberly and Marshall (2), and Bunnell, et al (1), by applying Equation (1) when no reaction takes place; that is, when a is zero. Results of Bunnell and co-workers have been used in this investigation because they are based upon experimental conditions similar to those applying to the conversion data given in Table 1. These thermal conductivities as well as those of Coberly and Marshall were computed by the following two-step process: (1) evaluating the ratio (K_e/cG) from experimental temperature data as indicated by Equation (1) with $a = 0$, and (2) obtaining a K_e value by multiplying this ratio by the specific heat and mean mass velocity, G_o, based upon the area of the empty reactor. This procedure gives a true thermal conductivity only if the local mass velocity in the packed bed is always equal to G_o. When such K_e data, actually equal to $\left(\frac{K_e}{cG}\right) cG_o$ were plotted vs. G_o, straight lines were obtained. Since this procedure is equivalent to plotting a variable against itself, a more appropriate procedure for finding the effect of mass velocity on K_e would be to plot the group (K_e/cG) vs. G_o or a modified Reynolds number (d_pG_o/μ). Data of Bunnell have been replotted on this basis in Figure 3 and indicate the following type of relationship:

$$\left(\frac{K_e}{cG}\right) = a\left(\frac{d_pG_o}{\mu}\right)^{-0.51} \qquad (3)^*$$

where a is a function of radial position. Recent velocity measurements in packed tubes (7) show a sharp decrease in velocity as the tube wall is approached, and this is believed to be the explanation for the similar decrease in (K_e/cG) near the reactor wall. From the center of the reactor to a radial position (r/r_o) of 0.7 there is no significant trend in values of K_e/cG. It is not possible to determine the exact effect of mass velocity on effective thermal conductivity from Equation (3), because G is not necessarily equal to G_o. However, the assumption that G is proportional to G_o is probably not greatly in error. Then Equation (3) indicates that K_e is proportional to the one-half power of the mass velocity. This is in approximate agreement with the results of Hougen and Piret (5) who measured average values of K_e for the entire bed. Since the resistance to heat transfer in the radial direction is determined primarily by the conduction and convection resistances in the gaseous regions around the pellets, effective thermal conductivities should be similar to heat-transfer coefficients between gases and solid pellets. From this viewpoint Equation (3) is in agreement with the results of Wilke and Hougen (9) who found that such heat-transfer coefficients were proportional to the 0.5 power of the mass velocity.

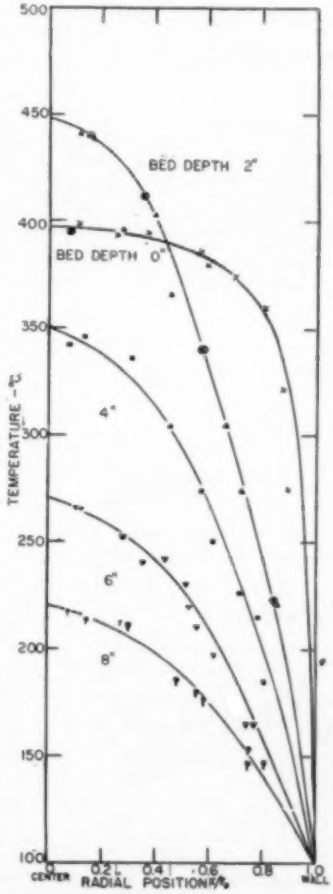

Fig. 2. Temperature vs. radial position for gas mass velocity of 244 lbs./(hr.)(sq.ft.)

* Equation (3) is not applicable over a wide range of mass velocities. For example, under conditions of high mass velocities, K_e/cG should be independent of the modified Reynolds number.

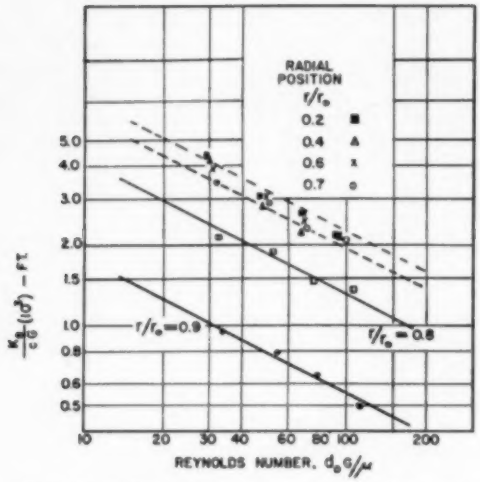

Fig. 3. Correlation of effective thermal conductivity data.

It may appear that evaluating (K_e/cG) from Equation (1) is a rather inaccurate approach since second-order as well as first-order differentials must be evaluated graphically. However, the precision of these slopes can be checked in an over-all way by using the K_e/cG values in the numerical solution of Equation (1) (with $\alpha = 0$) by the method described later in the paper. If the temperature distribution obtained in this numerical solution agrees with the original temperature data, the K_e/cG values are correct. If not, adjustments can be made until the computed and experimental temperatures are in reasonable agreement. The K_e/cG values shown in Figure 3 have been corrected in this manner, and the comparison of experimental and computed temperatures are shown in Figure 4 for a mass velocity of 244 lb./(hr.)(sq.ft.).

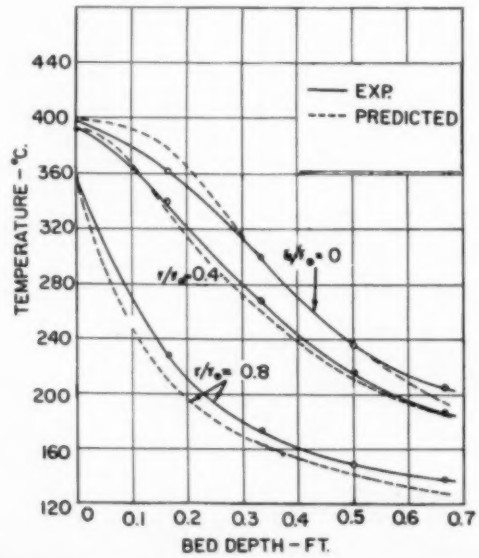

Fig. 4. Experimental and predicted temperatures without reaction. Mass velocity = 244.

It is clear from Equation (1) that effective thermal conductivity values themselves are not needed to evaluate the temperature in a reactor, but only the values of group K_e/cG. However, the assumption of a constant mass velocity in the heat of reaction term $\alpha\beta q/cG$ is necessary for the solution of Equation (1) until reliable data are available for the variation in G with radial position. Accordingly, in this paper, the data shown in Figure 3 have been used for K_e/cG and the mass velocity in the term $\alpha\beta q/cG$ is assumed equal to G_0.

Design Method

Basic Grossman Method. Noting the difficulty in attempting to solve Equations (1) and (2) analytically, Grossman (3) suggested a numerical-graphical approach based upon rewriting Equation (1) in difference form as follows:

$$\Delta_z t = \left(\frac{K_e}{cG}\right)\frac{\Delta z}{(\Delta r)^2}\left[\Delta^2_r t + \frac{\Delta r}{r}\Delta_r t\right] + \left(\frac{\alpha\beta q}{cG_0}\right)\Delta z \qquad (4)$$

or

$$\Delta_z t = t_{n,k+1} - t_{n,k} = \frac{1}{2}\left[t_{n+1,k} + t_{n-1,k} - 2t_{n,k} + \frac{1}{2n}(t_{n+1,k} - t_{n-1,k})\right] + \frac{\alpha\beta q}{cG_0}\Delta z \qquad (5)$$

In Equation (5) n represents the number of radial increments, Δr in size, measured from the center of the reactor $[r = (\Delta r)n]$ and k the number of axial or bed-depth increments, Δz, measured from the entrance to the reactor. In proceeding from Equation (4) to (5) the independent choice of the size of Δr and Δz has been eliminated since it is necessary that

$$\left(\frac{K_e}{cG}\right)\frac{\Delta z}{(\Delta r)^2} = \tfrac{1}{2} \qquad (6)$$

It is apparent that the part of Equation (5) in brackets contains only temperatures at the k level of bed depth. Hence $t_{n,k+1}$ can be determined by Equation (5), and therefore, the temp rature at any bed depth, by successive application of (4). In this calculation it is necessary to evaluate the temperature rise due to reaction,

$$\frac{\alpha\beta q}{cG_0}\Delta z$$

Rigorously, α depends upon an average value of t in the increment of bed depth

from k to $k+1$. However, this difficulty can be avoided by assuming such an average value, calculating $t_{n,k+1}$ from Equation (5), and then checking the original assumption by an arithmetic averaging procedure. The restrictive relationship between Δz and Δr imposed by Equation (6) is not a definite requirement, but the simplication obtained in Equation (5) because of this restriction greatly decreases the numerical work in carrying out a solution. In addition Grossman showed that, with the limitation of Equation (6), $t_{n,k+1}$ could be obtained approximately by the following graphical procedure: (1), connecting $t_{n-1,k}$ and $t_{n+1,k}$ with a straight line on a plot of temperature vs. ln (n); (2), reading the temperature at n; and (3), adding to this value the temperature rise due to the reaction, that is,

$$\frac{a\beta q}{cG_o}\Delta z$$

Once the radial temperature distribution is known, the conversion in the volume increment ($2\pi r\Delta r\Delta z$) can be found by writing Equation (2) in difference form

$$\Delta x = \frac{a_{avg}\beta(2\pi r\Delta r)\Delta z}{F} \qquad (7)$$

This basic Grossman method is described in detail by Hougen and Watson (6). It was applied by Hall and Smith (4) with not very satisfactory results. While part of the reason for the poor agreement between predicted and experimental temperatures was the use of a constant K_e value rather than one which varied with radial position (Fig. 3), some of the difficulty was due to the mechanical problems in applying the Grossman approach. These are discussed in the following sections.

Non-Uniform Bed Depth Increments. Data in Figure 3 show that K_e/cG is approximately halved in proceeding from the center of the reactor out to a radial position $r/ro = 0.8$. This requires a corresponding increase in the bed depth increment, Δz, in accordance with Equation (6). Application of Equation (5) gives temperatures across the radius of the bed at the same bed depth increment, $k+1$, but at actual bed depths which are increasing as the tube wall is approached. In the subsequent applications of Equation (5) to the next bed depth increment, all the temperatures on the right-hand side must be at the same actual bed depth, for otherwise the restriction of constant depth on the derivatives with respect to

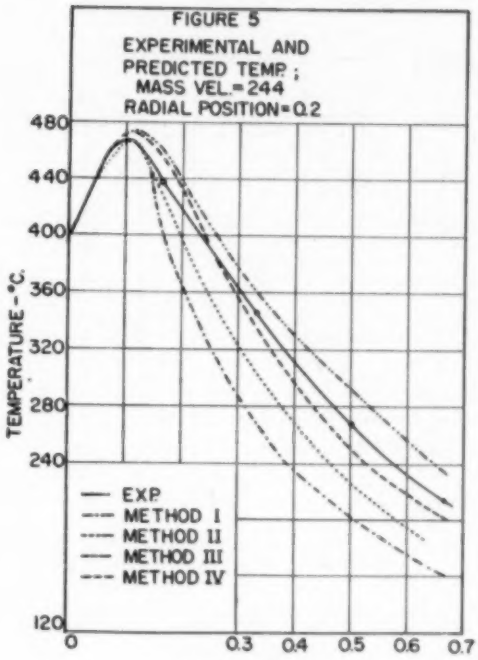

Fig. 5.

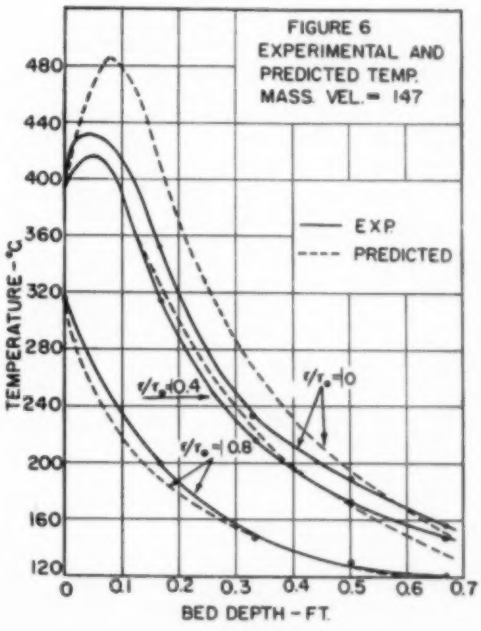

Fig. 6.

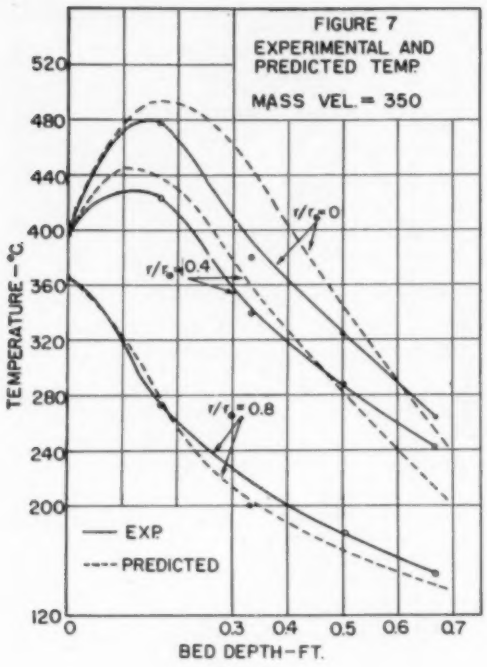

Fig. 7.

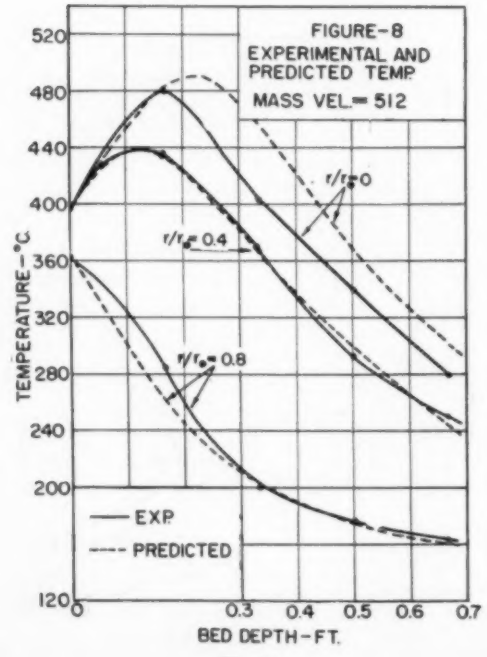

Fig. 8.

r (Eq. (1)) is not met. This adjustment to a uniform bed depth after each increment can be made in a variety of ways. It is suggested that, in general, satisfactory results can be obtained by linear interpolation or extrapolation.

The magnitude of the error introduced by not making the bed-depth correction is illustrated in Figure 5 where experimental and computed temperatures are plotted vs. catalyst bed depth for a radial position of $r/r_o = 0.2$ and a mass velocity, $G_o = 244$ lb./(hr.)(sq. ft.). The curves for Method I were determined by the basic Grossman approach previously described, and those for Method II represent the results obtained by adjusting to a constant bed depth. In view of the improved agreement of Method II with the experimental results, Methods III and IV, discussed in the next section, also include the bed-depth correction procedure.

Temperatures Near Center of Reactor. Equation (5) cannot be used to evaluate the temperature at the center of the reactor, because $n = o$. Hougen and Watson (*6*) have suggested that the center temperature be determined by the expression

$$t_{o,k+1} - t_{o,k} = t_{1,k} - t_{o,k} + \left(\frac{a\beta q}{cG_o}\right)\Delta z \qquad (8)$$

or

$$t_{o,k+1} = t_{1,k} + \left(\frac{a\beta q}{cG_o}\right)\Delta z \qquad (9)$$

Equation (9) is based upon the fact that the temperature distribution in a cylindrical reactor should be symmetrical about the axis and that the Grossman graphical approach may be assumed applicable to radial positions $n = 1$ and $n = -1$. Under these circumstances a horizontal line is obtained between $n = 1$ and $n = -1$ on a plot of t vs. $ln(n)$, and Equation (9) follows directly.

Three other methods of obtaining the center temperature have been considered in this work:

1. Extrapolation of a curve of t vs. r/r_o to the center of the reactor

2. Calculation by the equation

$$t_{o,k+1} - t_{o,k} = \tfrac{1}{2}(t_{1,k} - t_{o,k}) + \left(\frac{a\beta q}{cG_o}\right)\Delta z \qquad (10)$$

This expression rests upon the assumption that the t vs. r/r_o curve is parabolic in nature when no reaction occurs. This is seen to be qualitatively justified from the data shown in Figure 2.

3. Calculation by the equation

$$t_{n,s+1} - t_{n,s} = \tfrac{1}{4}(t_{1,s} - t_{0,s}) + \left(\frac{a\beta q}{cG_o}\right)\Delta z \qquad (11)$$

This expression is based upon the assumption that a straight-line relationship exists between t and $\ln(n)$ and that, as far as average temperatures are concerned, the actual boundaries of the radial increments are not at $n = 1$, $n = 2$, etc., but midway between these values.

At the radial position $n = 1$, the graphical approach is not applicable because $\ln 0$ is negative infinity. In this instance Hougen and Watson (6) have assumed that $t_{1,s+1}$ can be evaluated by an expression similar to that used for $n = 0$; namely,

$$t_{1,s+1} = t_{1,s} + \left(\frac{a\beta q}{cG_o}\right)\Delta z \qquad (12)$$

Actually it is not necessary to make any assumptions at $n = 1$, since Equation (5) is applicable and gives for $t_{1,s+1}$ the following result:

$$t_{1,s+1} = \tfrac{1}{2}[t_{0,s} + t_{0,s} + \tfrac{1}{2}(t_{0,s} - t_{0,s})] + \left(\frac{a\beta q}{cG_o}\right)\Delta z \qquad (13)$$

The effects of some of these different methods of obtaining the temperature near the center of the reactor upon the over-all results are shown in Figure 5. In Methods I and II Equations (9) and (12), were used to evaluate the temperature at $n = 0$ and $n = 1$. In Method IV Equation (9) was used for $t_{0,s}+1$ but Equation (13) for $t_{1,s+1}$. The better agreement with experimental data obtained in Method IV indicates that Equation (13) is more reliable than (12) for obtaining temperatures at the first radial increment.

Method III was based upon Equation (13) for $t_{1,s+1}$, but the center temperature was evaluated from Equation (11). Equations (9) and (11) give $t_{0,s+1}$ values which are the furthest apart. Therefore, the curves for Methods III and IV shown in Figure 5 represent the maximum effect of different methods for determining the center temperature. Curves based upon the extrapolation method or Equation (10) lie between those for Methods III and IV. From this comparison of experimental and computed results at a radial position of 0.2, Method IV is concluded to be the most reliable. A similar comparison at the center of the bed indicates the same result, but at positions closer to the tube wall, center temperatures evaluated by Equation (10) lead to better agreement with the observed data. However, the effect of the center temperature on temperatures near the wall of the reactor is small in any event.

Results

Using Method IV as the preferred design procedure, temperatures and conversions were computed at all four mass velocities for comparison with the experimental results. In these calculations the radius of the tube was divided into five radial increments, so that $\Delta r = 0.2(1.03) = 0.206$ in. This choice fixed the relationship between the bed-depth increment and (Δr) in accordance with Equation (6). The decision to use five radial increments was the result of a compromise between the precision desired and the time required for the calculations. Ten increments would have increased by eightfold the time necessary for one design calculation.

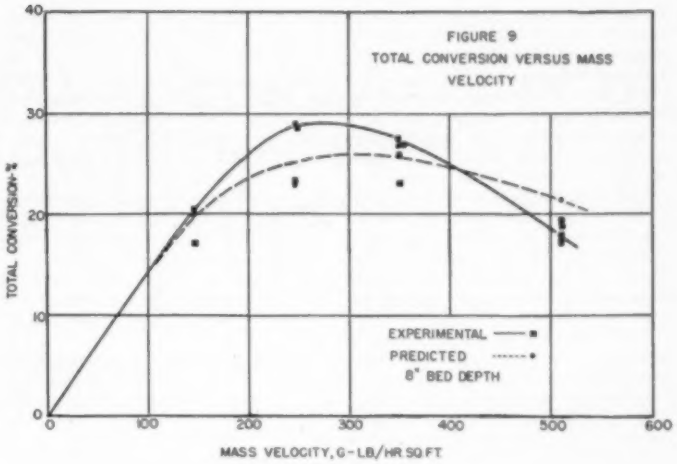

Fig. 9.

Observed and computed temperatures are shown in Figures 6, 7, and 8 for three radial positions and for mass velocities of 147, 350, and 512 lb./(hr.)(sq.ft.). In view of the large radial temperature gradients involved, and the general complexity of the problem, it is believed that the agreement is sufficiently good to lend validity to the modified Grossman design method. At radial positions other than the center of the bed (data at r/r_o of 0.2 and 0.6 are not shown in Figures 6-8, but the results are similar to those for r/r_o of 0.4 and 0.8), the maximum deviation is 21° C. while the average deviation is approximately 4° C. At the center of the bed, a maximum deviation of 60°C. is observed at the lowest mass velocity and low bed depths. It is believed that the deviation is due somewhat to the uncertainty in the method of predicting center temperatures, but primarily because of the relatively small number of radial increments used in the calculations.

After each bed-depth increment the bulk mean conversion was found by graphically integrating, with respect to cross-sectional area, the local conversion values obtained from Equation (7). This integration can be indicated by the equation,

$$\Delta x \text{ (bulk mean)} = \frac{1}{r_o^2}\int_0^{r_o} (\Delta x), 2r dr \qquad (14)$$

A comparison of bulk mean conversions so computed for the entire catalyst bed (nominal bed depth of 8 in.) with the experimental data is shown in Figure 9. The computed curve (shown dotted) has the same general shape as the curve through the experimental points, and also the agreement between the two is reasonably good. The multiple experimental points at each mass velocity represent the runs made with different beds of catalyst, not simply check runs with the same bed. As such, the data indicate the degree of reproducibility of catalyst activity and packing conditions. These conversion results are summarized also in Table 2. The agreement between predicted and experimental conversion is particularly interesting, because the calculation procedures neglect mass transfer radially, but not heat transfer. This suggests that the multiplicity of mechanisms by which heat can be transferred radially in a packed bed places heat transfer in a

TABLE 2.—COMPARISON OF PREDICTED AND EXPERIMENTAL CONVERSIONS (Maximum Values)

Mass Velocity of Gas lb./(hr.)(sq.ft.)	Conversion of SO_2 to SO_3—% Experimental	Predicted
147	20.7 17.2	19.8
244	28.7 23.2 29.0	23.0
350	27.2 22.2 27.5 26.3	26.9
512	18.2 19.2 17.7 16.8	21.6

more important position than mass transfer, which can occur only by molecular diffusion and turbulent diffusion processes.

To predict the temperature and conversion at one mass velocity and for a catalyst bed depth of 8 in. required about 15-hrs. time by the modified Grossman method proposed in this paper. A simplified procedure which would give almost as good results would be valuable from the viewpoint of the engineer in industry. It is hoped that such a procedure can be developed as more experimental data on fixed-bed reactors become available.

The method proposed here can be employed also to compute temperatures in packed beds under conditions of no reaction by setting a equal to zero. This approach has been used to check values of (K_e/cG) by comparing the temperatures so computed with experimental temperature data. Figure 4 is typical of the results obtained.

Conclusions

Temperatures have been measured as a function of mass velocity, radial position, and catalyst bed depth in a fixed-bed reactor operating with large radial temperature gradients. Conversion data also have been determined.

A modified Grossman method is proposed for predicting temperatures and conversions in fixed-bed reactors. This design method gives results which agree well with the experimental data. The procedure differs from the basic Grossman approach primarily in two ways:

1. Due to the variation in (K_e/cG) with radial position, the conventional method must be adjusted to give temperatures at a uniform bed depth after each bed-depth increment.
2. A numerical method is used to evaluate the temperature at the first radial increment out from the center of the bed.

Acknowledgment

The authors wish to acknowledge the financial assistance and generous cooperation received from The Texas Co. in carrying on this work.

Notation

a = coefficient in effective thermal conductivity correlation, Eq. (3)

A_c = cross-sectional area of empty reactor, sq.ft.

c = specific heat at constant pressure, B.t.u./(lb.)(° F.)

F = sulfur dioxide feed rate, moles/hr.

k = number of bed-depth increments, defined as $k = z/\Delta z$

G = mass velocity of gas at any point in reactor, lb./(hr.)(sq.ft.); G_a—mean mass velocity, equal to the mass-flow rate divided by A_c

K_e = effective thermal conductivity, B.t.u./(hr.)(ft.)(° F.)

n = number of radial increments; defined as $n = r/\Delta r$

q = heat evolved per mole of reaction, B.t.u./lb. mole

r = radial distance from center of reactor; r_a—radius of reactor; (Δr)—radial increment

t = temperature; $t_{n,k}$—temperature at a position in reactor characterized by a radial position of n increments and a bed depth of k increments

x = conversion; fraction of sulfur dioxide in feed converted to sulfur trioxide; Δx_r = conversion in a bed-depth increment Δz at a radial position r

z = axial distance from entrance of reactor, i.e., catalyst bed depth; Δz—bed-depth increment

α = specific reaction rate, lb.moles of sulfur dioxide converted/(hr.)(lb. of catalyst)

β = bulk density of catalyst, lb./cu.ft. of reactor volume

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Discussion

S. C. Ogburn, Jr. (Foote Mineral Co., Philadelphia, Pa.): In the Grossman-type calculations were corrections applied for the variation of K_e with radial position?

H. B. Irvin: Figure 3 illustrates the variation of K_e/cG with Reynolds' number and radial position. The particular value of the group K_e/cG corresponding to the radial position and Reynolds' number involved was used in making calculations.

S. C. Ogburn: Were conductivity measurements being used to estimate mass velocity differences across the axis?

H. B. Irvin: No attempt was made in this study to determine the values of the individual components of the group K_e/cG.

S. C. Ogburn: For runs with reaction, the temperature gradients reversed as the gases passed through the reactor. What effect would this reversal of the temperature gradient have on thermal conductivity and velocity profiles?

H. B. Irvin: Temperature gradients reversed only in the axial, or vertical, direction and not in the radial direction. The axial temperature gradients were small compared to the radial gradients, indicating only relatively small heat transfer axially by thermal conductivity; therefore, axial thermal conductivity was neglected in the calculations. No work was done on the effects of temperature gradients on velocity profiles.

D. M. Hurt (Du Pont Co., Inc., Wilmington, Del.): You mentioned in regard to some recent work in the velocity distribution at Purdue University that you found higher velocities near the center of the tube. Were these measured in a shallow bed or a relatively deep bed?

H. B. Irvin: The velocities were measured in a 2-in. I.D. tube at bed depths from 6 to 18 in.

D. M. Hurt: Such a velocity distribution might be possible in a shallow bed, but in a deep bed the velocity might be faster near the periphery. This comment is based upon observations by personnel of our company.

H. B. Ogburn (Atlantic Refining Co., Philadelphia, Pa.): Recent work at Princeton has yielded indications that the direction of the radial temperature gradients existent in packed bed heat exchangers has a pronounced effect on thermal conductivity measurements under given fluid dynamic conditions. This effect could conceivably be caused by changes in the velocity profile across the bed. Would you care to comment on this possibility in view of the presently reported work?

H. B. Irvin: It is believed that a significant part of the radial variation in the effective thermal conductivity observed in the present work is actually due to radial variations in mass velocity.

(*Presented at Minneapolis (Minn.) Meeting.*)

EFFECTIVE THERMAL CONDUCTIVITY OF GRANULAR SOLIDS THROUGH WHICH GASES ARE FLOWING

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Extensive data obtained on the cooling of air during downward flow through radially cooled beds of granular solids were analyzed by means of the classical equations for unsteady transfer of heat by conduction and the results interpreted as effective thermal conductivities of the granular beds.

The solids investigated included five sizes of Celite cylinders, and two sizes of spherical Celite pellets. Flow rates covered a 50-fold range in mass velocity, from 75 to 3700 lbs./(hr.)(sq. ft.), and initial air temperatures were varied from 75 to 800° F. The mixed outlet air temperature was measured. The cooling water around the tube was maintained near 60° F. Exhaustive studies of two sizes of cylindrical beds were made and some data on two other sizes were collected. Bed dimensions varied from 3.75 in. in diameter and 12.5 in. long to 1.37 in. in diameter and 6.43 in. long.

A generalized correlation for the thermal conductivity data was developed which may be written

$$\frac{k_e}{C_{pm}\mu_m} = \frac{3.7}{Fe}\,(R_p)^{1/5}$$

Conductivities for the air-Celite systems varied from 0.30 to 2.30 B.t.u./(hr.)(sq.ft.)(°F./ft.) in the range of variables studied. These values are from 20 to 100 times that of the fluid in the static state and from 2 to 15 times as great as the solid itself.

THE industrial processes in which fluids are caused to flow through granular solids are manifold and it was to fulfill the need for quantitative heat-transfer data applicable to these processes that the present investigation was undertaken. Typical industrial processes utilizing this mechanism include the combustion of granular materials such as coke or coal in grate furnaces, blast-furnace smelting of ores, producer gas manufacture, regenerative cyclic heating, calcination of limestone, through-circulation drying of granular solids, and catalytic processes in which reactions are promoted by catalyst-containing solids.

The published work of previous investigators on the thermal properties of packed beds quite naturally divides itself into studies of static systems (*29, 45, 47*), and studies of dynamic systems. Theoretical treatment of the mechanism of heat transfer between flowing gases and granular solids have been frequently attempted (*1, 2, 36, 40, 46*), and considerable experimental data for such systems are available (*12-16, 27, 35, 39, 42, 48*). However, fewer studies have been made for flow conditions in which the results have been interpreted as thermal properties of the system. Based on the gross heat transfer through the retaining wall, effective over-all heat-transfer coefficients were found and correlated by Colburn (*8*), Leva (*32*) and Leva and co-workers (*33, 34*). Using measured radial and longitudinal temperature gradients within the bed, Smith and co-workers (*5, 20*) and Coberly and Marshall (*7*) expressed their results as effective thermal conductivities. Recently Verschoor and Schuit (*44*) using average values of wall and terminal gas temperatures, as was done in the present work, obtained average conductivity data for the case of heating of the gas. These recent studies, especially those of Smith (*5, 20*) and Coberly and Marshall (*7*) indicate that the heat-transfer processes, even when no reactions are occurring within the bed, may be complicated by wall effects and by variations in temperature occurring along the radii of packed beds. The temperature patterns are functions of the length and diameter of the beds as well as the size and composition of the solid particles, and are furthermore somewhat affected by the packing arrangement. Techniques used by Arthur *et al* (*3*) to study processes occurring within the bed are particularly interesting.

The present study was restricted to the measurement of the over-all heat transfer from the hot air passing through the packing to the water-cooled walls. An attempt was made to secure carefully taken data over as wide a range of experimental conditions as possible. Results are correlated in terms of an over-all effective thermal conductivity.

Theoretical

The following assumptions were made: (a) uniform air velocity distribution across the bed diameter, (b) total resistance to heat transfer at and through the metal walls of the confining cylinder is negligible, and (c) radiant

Tables 10-24 are on file (Document 3243) with the American Documentation Institute, 1719 N Street, Northwest, Washington, D. C. Obtainable by remitting $1.00 for microfilm and $6.30 for photocopies. Data for this paper also available from University of Minnesota.

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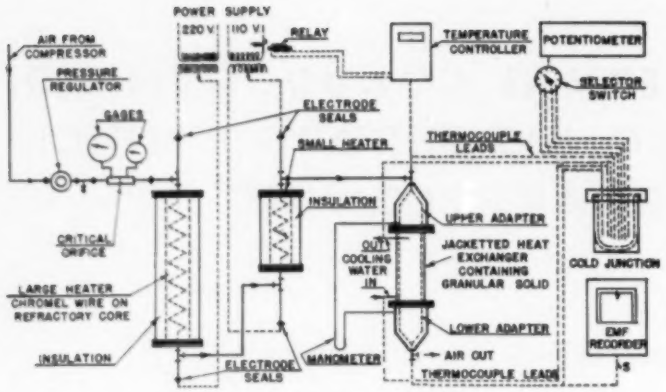

Fig. 1. Diagram of apparatus.

heat transfer and heat flow in a direction parallel to the direction of fluid flow are inconsequential. Then the effective thermal conductivity, k_e, was evaluated by applying the Fourier (*11*) equation for unsteady heat conduction from convex surfaces of infinite lengths:

$$\frac{\partial t}{\partial \theta} = K\left(\frac{\partial^2 t}{\partial r^2} + \frac{1}{r}\frac{\partial t}{\partial r}\right) \qquad (1)$$

where K, the thermal diffusivity, is equal to $k_e/\rho C_p$. A convenient solution of this differential equation is that of Bowman (*4*). For the particular boundary conditions the result is the Fourier-Bessel expansion:

$$\frac{t - t_s}{t_o - t_s} = 2\sum_{i=1}^{\infty} \frac{1}{a_i J_1(a_i)}\, e^{-K\left(\frac{a_i}{a}\right)^2 \theta} \cdot J_0\left(\frac{a_i r}{a}\right) \qquad (2)$$

Here t is the value of the temperature at radius r and time θ, t_o is the average inlet gas temperature, and t_s is the average constant temperature of the wall surface. J_o indicates a Bessel function of zeroth order, and J_1 the Bessel function of first order. a_1 is the smallest value of $J_o(x)$ which gives $J_o(x) = 0$, a_2 is the next larger value, etc. (*19*).

The time, θ, may be replaced by the expression $Fe\rho_{ave}Z/G$, thus introducing the depth of bed, Z, the fractional void volume, Fe, the superficial mass velocity, G, and the average gas density, ρ_{ave}.

Equation (2) may then be written as

$$\frac{t - t_s}{t_o - t_s} = 2\sum_{i=1}^{\infty} \frac{J_o\frac{a_i r}{a}}{a_i J_1(a_i)}\, e^{-\frac{k_e FeZ}{C_{pm} G a^2} a_i^2} \qquad (3)$$

in which, since $K = k_e/C_p\rho_{ave}$, it is to be noted that the density term does not appear.

Denoting the right-hand side of Equation (3) as Series R,

$$\frac{t - t_s}{t_o - t_s} = \text{Series } R \qquad (4)$$

In view of the difficulty of accurately measuring temperatures within the packed bed, it is advantageous to use an average temperature of the outlet gas. That an average outlet gas temperature can be utilized to obtain an over-all effective thermal conductivity can be seen by making two calculations of the heat contained above the surface temperature in a differential slice of the gas taken at the exit end of the cylinder. Thus

$$dQ = \int_o^a (t - t_s) C_p \rho 2\pi r dZ dr \qquad (5)$$

But since, from Equation (4)

$$(t - t_s) = (t_o - t_s) \text{ Series } R \qquad (6)$$

$$dQ = (t_o - t_s) 2\pi \int_o^a C_p \rho \text{ Series } R\, r dZ dr \qquad (7)$$

can be written. However, the average temperature, t_a, of the slice may be defined such that

$$dQ = (t_a - t_s)\rho C_p \pi a^2 dZ \qquad (8)$$

hence, upon equating to Equation (7) one obtains:

$$\frac{t_a - t_s}{t_o - t_s} = \frac{2}{a^2}\int_o^a \text{Series } R\, r dr \qquad (9)$$

This result is entirely analogous to that obtained by Newman (*38, 6*) in his application of diffusion equations to the drying of porous solids, wherein his term, k, is replaced by $k_e/C_p\rho_{ave}$ and his concentrations by temperatures. Graetz (*17, 18*) also used a similar approach in determining the thermal conductivities of liquids flowing in empty tubes.

Upon the evaluation of the integral in Equation (9)

$$\frac{t_a - t_s}{t_o - t_s} = 4\sum_{i=1}^{\infty} \frac{1}{a_i^2}\, e^{-a_i^2\left(\frac{k_e FeZ}{C_{pm} G a^2}\right)} \qquad (10)$$

is obtained, a result identical to that of Newman's except for the just-mentioned substitutions.

Letting the right-hand side be represented by Series R' and setting the left-hand side equal to E,

$$E = \frac{t_a - t_s}{t_o - t_s} = \text{Series } R' \qquad (11)$$

Inspection of Equation (10) shows that

$$E = f\left(\frac{k_e FeZ}{C_{pm} a^2 G}\right) = f\left(\frac{4k_e FeZ}{C_{pm} D_c^2 G}\right) = f\left(\frac{k_e FeZ\pi}{C_{pm} w}\right) \qquad (12)$$

Since E is readily evaluated experimentally and since for a given solid, flow rate, temperature level and bed dimensions, Fe, w, G, C_p, Z, and a are known, the value of the over-all effective thermal conductivity, k_e, can be determined from Equation (10) or (11). Newman has evaluated the temperature ratio, E, for various values of a parameter, identical to $k_e FeZ/C_{pm} a^2 G$. A plot of this evaluation, called the E chart, is given in Figure 4. The group, $C_{pm} a^2 G/k_e FeZ$, shall be referred to as the modified Graetz number, Gz', by virtue of its analogy to the more familiar group, $\rho C_p \pi a^2/k\theta$, which bears that name (*30*).

Equipment and Methods

The apparatus used in this work is shown schematically in Figure 1. Details of the

entrance and exit adapters for the heat exchangers are shown in Figures 2 and 3.

The flow of compressed air at an automatically controlled upstream pressure was metered by passage through an appropriate critical orifice (10) which had been carefully calibrated against a gasometer using a low vapor pressure oil as the sealing liquid.

For heating the air stream going to the packed bed, two electrical heaters were employed. Generally the input to the larger heater was adjusted just short of requirements and the smaller automatically controlled heater was used to supply the remaining duty. The temperature controller was a Wheelco Capacitrol provided with a Claud S. Gordon Xactline auxiliary unit to increase its sensitivity. Control was always of the order of ±1/10° F. In order to indicate when a steady state had been attained, the e.m.f. of six uniformly spaced thermocouples connected in parallel located in the effluent air stream was continuously recorded.

The jacketed heat exchanger containing the granular material was provided with adapters on either end. The flow of air was always downward. The adapters consisted of a 3-in. long conical section, which brought the internal diameter from 1 in. up to 3¾ in. followed by a 3-in. long cylindrical section, 3¾ in. in diameter, flanged at the end. This flange was secured to a companion flange attached to the jacketed cylindrical exchanger in which the pellets were contained. The exterior surfaces of the adapters were insulated. Prior to entering the granular bed the air passed through two perforated ¼-in. Transite plates which occupied the entire cross section of flow. The perforations in the top plate consisted of seven symmetrically located ½-in. diameter holes below each of which the junctions of No. 28 B & S gage chromel-alumel thermocouples terminated. These seven couples were contained in small refractory insulators, the lower ends of which were fixed in the second Transite plate. This lower plate was provided with numerous ½-in. holes to allow free flow of the air. This arrangement was used to obtain uniform flow and temperature distribution, which as has recently been shown (*3*) is of importance, especially for short beds. Details of the upper adapter are shown in Figure 2. The thermocouple leads were taken back upward through the Transite plates and brought out through a seal in the top of the adapter. The leads from six of the thermocouple junctions located below the circle of orifices were arranged in a parallel circuit. Average inlet and also outlet temperatures of the air were computed as one-seventh of the sum of the temperature indicated by the single centrally located couple and six times that of the six parallel couples. In view of the fact that leads of the parallel couples were of equal length and hence of equal conductance, this procedure is permissible (*9*). To reduce radiation error three concentric cylindrical aluminum foil radiation shields spaced about ½ in. apart were placed around the thermocouple assembly between the Transite plates. A single cylindrical shield was mounted on the top Transite plate circumscribing the orifices and extending upward about 1½ in.

The 20-mesh screen by which the pellets were supported was soldered on its periphery to the end of the exchanger. Immediately below the screen was a set of four concentric cylinders 1 in. in length (Fig. 3). These served as straightening vanes, the purpose of which was to prevent subsequent mixing from influencing the flow pattern in the lower portion of the granular bed.

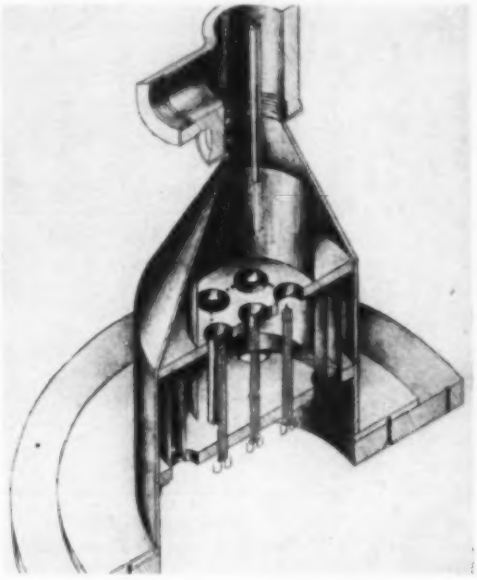

Fig. 2. Isometric half section of top adapter. Shows orifice plate, radiation shields and location of thermocouples.

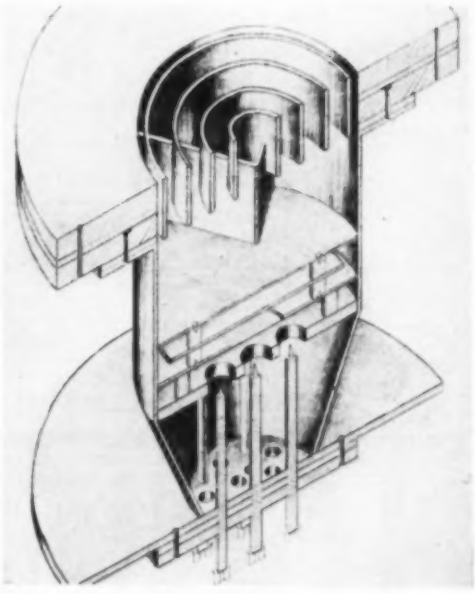

Fig. 3. Isometric half section of bottom adapter. Shows straightening vanes, mixing device, and location of thermocouples.

TABLE 1.—*B* VALUES FROM FIGURE 5

in.	Pellet	*B*	a_p, sq.ft.
1/16	Celite Spheres	2.85	.000177
⅛	Celite Spheres	3.75	.000314
⅛	Celite Cylinders	4.6	.00050
3/16	Celite Cylinders	7.1	.00110
¼	Celite Cylinders	10.0	.00221
⅜	Celite Cylinders	13.0	.00444
⅜ × ⅛	Celite Cylinders	12.5	.00565

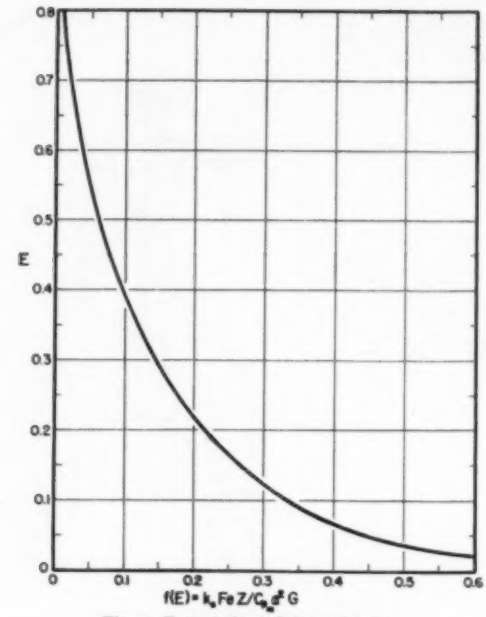

Fig. 4. E chart for infinite cylinders.

TABLE 2.—EFFECT OF BED DIAMETER ON COEFFICIENT *B*

Bed Dimensions, ft. Diameter	Length	Pellet in. Size	*B*	Taken from
0.114	.535	¼ cylinders	14.0	Fig. 7, Line *C*
0.198	.539	⅛ cylinders	4.6	Fig. 5
0.313	.539	⅛ cylinders	1.33	Fig. 7, Line *A*
0.313	.539	¼ cylinders	2.0	Fig. 7, Line *B*

TABLE 3.—EFFECT OF BED DIAMETER ON COEFFICIENT *b*

Bed Diameter, D_e, ft.	*b*	Taken from
0.114	635	Line *C*, Fig. 6
0.198	209	Line *A*, Fig. 6
0.313	61	Line *B*, Fig. 6

TABLE 4.—EFFECT OF BED DEPTH ON COEFFICIENT *M*

Bed Depth *Z*, ft.	*M* (Value of *b* where $D_e = 1$, Fig. 8)
0.539	8
1.04	15

TABLE 5.—PROPERTIES OF CELITE CYLINDERS USED

Size in.	Shape	Diam., ft.	Height, ft.	Area, a_p, ft.²/ pellet	Void Vol., %	Apparent Density, lb./cu.ft.
⅜ × ⅜	Cylinders	.0320	.0402	.00565	39.5	....
⅜	Cylinders	.0319	.0283	.00444	36.1	33.1
¼	Cylinders	.0214	.0234	.00231	34.2	38.2
3/16	Cylinders	.0159	.0141	.00110	43.6	....
⅛	Cylinders	.0103	.0103	.00050	37.5	38.2
1/16	Spheres	.0075	.....	.000177	41.5	....
⅛	Spheres	.0100	.....	.000314	41.6	....

TABLE 6

SCOPE OF VARIABLES INVESTIGATED, RESULTS OF WHICH APPEAR IN FIGURE 10

Cooling of Air in Downward Flow Through Beds of Celite Pellets

Bed Dimensions Dia.,	Depth	Pellet Size	Shape	Mass Velocity Range, lb/(hr)(ft²)	Range of Ave. Gas Temp., °F.	Run No.	Symbol
2.37*	6.46*	1/8*	Cylinders	721 - 2009	130 - 608	410 - 443	◆
2.37	6.46	3/16	Cylinders	728 - 1965	118 - 580	408 - 446	◆
2.37	6.46	1/8	Cylinders	1181 - 3740	108 - 574	337 - 395	◆
2.37	6.46	3/8	Cylinders	728 - 1978	125 - 532	365 - 404	◆
2.37	6.46	1/8	Spheres	719 - 1967	120 - 493	375 - 405	◆
2.37	6.46	1/16	Spheres	716 - 1960	139 - 507	4 - 676	◆
2.37	6.46	3/8*x1/2*	Cylinders	728 - 1982	133 - 479	375 - 401*	◆
3.75	12.5	1/8	Cylinders	70	80 - 271	80 - 96	●
3.75	12.5	1/8	Cylinders	163	86 - 347	98 - 105	●
3.75	12.5	1/8	Cylinders	285	87 - 386	106 - 116	●
3.75	12.5	1/8	Cylinders	466	87 - 469	117 - 125	●
3.75	12.5	1/8	Cylinders	785	96 - 563	130 - 150	●
3.75	12.5	1/8	Cylinders	732	105 - 556	333 - 337	■
3.75	12.5	3/8	Cylinders	930 - 2070	284 - 280	335 - 338	●
3.75	12.5	3/16	Cylinders	466 - 2064	250 - 280	339 - 342	●
3.75	12.5	1/8	Cylinders	491 - 2096	130 - 470	356 - 360**	●
						380 - 384**	●
3.75	6.46	1/8	Cylinders	290 - 1900	66 - 500	290 - 294	■
						317 - 327	■
3.75	6.46	1/8	Cylinders	491 - 1509	70 - 469	299 - 316**	●
						331 - 332**	●
1.37	6.46	1/8	Cylinders	846	67 - 364	280 - 287	●

* Not plotted in Fig. 10

** Data for low mass velocity runs (B = 491) only plotted in Fig. 10

TABLE A.

Diameter in.	Length in.
3.75	12.5
3.75	6.46
2.37	6.46
1.37	6.46

Mixing of the effluent gas to insure a correct average outlet temperature was obtained by passing the gas successively through 20-mesh screens, around the periphery of a circular baffle, and through two successive orifice plates. Below the second orifice plate the seven thermocouples used to measure the effluent air temperature were located.

Four easily interchanged, thin walled (1/16 in.) brass heat exchangers were used in this investigation. Since these exchangers were completely filled with pellets, these dimensions are also the dimensions of the pellet beds as shown in Table A.

In the ¼-in. annular space surrounding the inner cylinder ¼-in. copper tubing was spirally wound with a 1-in. pitch and soldered to the inner wall. This insured a definite path for the water between this tubing, effected a high rate of heat transfer and hence resulted in a negligible thermal resistance at this surface.

The water content of the entering air was measured by means of a wet-dry bulb psychrometer, and pressure corrected humidities (*22, 23*) determined. Fore pressures to the critical orifices were measured with a Bourdon-tube-type pressure gage previously calibrated against a dead weight tester. Viscosity data for dry air and water vapor were taken from the International Critical Tables (*21, 28, 41*), and the viscosity of mixtures of air and water vapor was computed assuming additive fluidities. These agreed with the plot of the Enskog-Chapman equation (*15*). Specific heat data (*24, 31*) were assumed to be additive.

Dimensions of the Celite cylinders (Table 5) were obtained by measuring with a micrometer 200 randomly selected pellets. Void volume was calculated as the difference between the total volume and the calculated volume of the pellets as determined by counting the number occupying a known volume. Total volume was determined in a receptacle of size sufficient to render wall effects negligible; that is, having a diameter at least ten times that of the largest dimension of the pellet. The receptacle was charged by adding a few pellets at a time and permitting these to come to rest before further additions. In this manner random dense packing is to be expected. A similar procedure was used in filling the heat exchangers. A slightly different procedure was employed in determining the dimensions of the Celite spheres. A known number of pellets thoroughly soaked with water was drained of superficial water and the pellet volume and void space determined by water displacement. From the volume of displaced water, and the number of pellets, the average spherical volume and diameter were calculated.

In addition the following information from the manufacturers of Celite (Johns-Manville) may be of interest.

Analysis of dried natural material, an amorphous opaline silica of diatomaceous origin:

	%
Combined water	4.0
SiO_2	88.0
Al_2O_3	4.0
Fe_2O_3	1.4
$Na_2O + K_2O$	1.5
$CaO + MgO$	1.0

This material is inorganic-bonded and calcined, the final product containing about 86.9% SiO_2.

Porosity of individual pellet	...60%
Mercury density of pellet	.....0.9
Water absorption capacity	.....60%
Surface area (internal)	.....2.4 m^2/g
Thermal conductivity of solid material in final form at 1000° F.	0.2 B.t.u./(hr.)/(sq.ft.)/(° F./ft.)

After the recorder showed constant outlet air temperature for at least 20 min., the necessary data were recorded. The time required to reach a state of equilibrium varied from 30 to 200 min. depending largely on the rate of flow, mass of pellets and to a lesser extent on the temperature level.

The range of the variables included in this study are given in Table 6. Approximately one tenth of the data obtained are given in Tables 7, 8, and 9; the remainder are available in the thesis of J. O. Hougen at the Library of the University of Minnesota or from the American Documentation Institute.

Analysis of Data

It was assumed that the effective thermal conductivity of the system depends upon the dimensions and composition of the solid material, and the physical and flow properties of the gas. Thus it was reasoned that a modified Reynolds number would be a pertinent variable. Surface area was considered to be an appropriate characteristic dimension since it was felt that a major resistance to radial heat transfer would arise by virtue of the gas films surrounding the pellets. On this basis the Reynolds number, R_p, was defined as $\sqrt{a_p}G/\mu_m$, where a_p is the surface area of the pellet, G the superficial mass velocity of the gas, and μ_m is the viscosity of the gas. The temperature finally selected at which to evaluate the fluid properties was the arithmetic average of inlet and outlet temperatures.

From the observations on 74 runs, Runs 410-483, values of $t_a - t_s/t_o - t_s$ were calculated and from an enlarged E chart, similar to Figure 4, the reciprocal of the modified Graetz numbers obtained. Values of k_s and R_p were also calculated. In this group of observations two sizes of Celite spheres and five sizes of Celite cylinders were used in a bed 2.37 in. in diameter and 6.46 in. in depth. Typical data are summarized in Table 7. With each size of pellet a series of runs was made at several mass velocities. At a given velocity, variations in the Reynolds number were effected by changing the temperature of the gas. Three to four different temperatures were used. In order to include the dimensions of the bed and its fractional void space the modified Graetz number was chosen as a pertinent variable. Using logarithmic coordinates, a plot of $1/G_z'$ vs. R_p gives the results shown in Figure 5.

TABLE 7

SUMMARY OF DATA

Packed Bed 2.37 Inches in Diameter and 6.46 Inches Deep

Run	θ	t_o	t_a	t_s	E	$1/Gz'$	k_s	R_p	$\frac{k_s}{c_p G_m}$	$\frac{1}{Y_o}(R_p)^{1/3}$
					1/8" Celite Cylinders					
410	1176	205.0	126.5	56.0	.473	.071	.98	531	81.9	21.6
412	1174	413.8	215.1	56.2	.444	.081	1.13	952	78.9	20.5
415	721.8	205.7	116.7	55.6	.407	.095	.80	328	67.3	18.4
418	720.9	627.0	258.7	56.5	.354	.117	1.02	249	62.7	16.8
421	2009	150.6	109.7	56.0	.568	.042	.98	950	86.4	26.2
423	1994	311.2	192.7	56.0	.536	.051	1.21	816	90.5	24.9
					3/16" Celite Cylinders					
424	730	205.7	110.8	55.7	.367	.112	.82	493	69.5	18.1
427	728	641.2	245.6	56.9	.323	.132	1.00	372	61.4	16.5
430	1177	511.3	239.8	56.2	.403	.098	1.19	636	78.1	19.7
433	1984	152.7	105.8	56.5	.513	.058	1.15	1331	102.0	25.6
436	1984	138.1	97.6	57.3	.501	.062	1.23	1414	110.0	25.5
					1/4" Celite Cylinders					
437	1984	331.8	187.2	57.1	.474	.071	1.55	1728	114.5	35.2
440	1181	820.4	327.4	56.8	.354	.117	1.59	794	87.1	27.1
443	1188	151.7	98.1	56.7	.436	.084	1.09	1218	96.6	31.4
446	3738	507.4	301.4	56.9	.543	.049	2.09	2863	132.0	41.5
					1/8" Celite Cylinders					
446	723	205.3	105.8	56.3	.332	.127	1.12	988	94.6	27.6
449	1171	150.2	95.4	56.7	.414	.093	1.31	1670	117.1	32.9
452	1977	725.5	338.9	58.4	.421	.091	2.28	1901	129.5	34.3
454	1978	143.3	98.4	55.9	.486	.067	1.60	2824	142.2	39.2
					1/8" Celite Spheres					
455	1976	116.9	90.7	55.5	.573	.041	.85	772	77.7	22.1
458	1173	409.6	219.0	56.4	.460	.076	.96	359	80.4	17.1
461	722	394.6	191.4	57.0	.398	.100	.77	257	66.9	14.9
465	1169	441.7	216.5	58.7	.447	.082	1.03	353	69.3	17.0
					1/16" Celite Spheres					
466	717	211.9	126.1	58.0	.443	.083	.63	193	52.4	14.0
469	1173	159.2	110.2	58.1	.515	.056	.69	328	60.3	16.6
472	1445	662.1	351.1	58.6	.485	.068	1.08	282	62.6	15.8
474	1445	407.1	238.3	57.6	.517	.058	.90	328	62.1	16.6

TABLE 8

SUMMARY OF DATA

Packed Beds 1.37 Inches and 3.75 Inches in Diameter and 6.43 Inches and 6.46 Inches Deep

Run	θ	t_o	t_a	t_s	E	$1/Gz'$	k_s	R_p	$\frac{k_s}{c_p G_m}$	$\frac{1}{Y_o}(R_p)^{1/3}$
					Bed Diameter 1.37", Depth 6.43"					
					1/8" Celite Cylinders					
281	648	107.4	65.4	56.2	.180	.238	.78	424	73.0	20.1
282	648	152.9	71.6	56.4	.158	.258	.85	410	76.6	19.8
284	648	289.9	89.3	55.5	.144	.276	.92	372	74.5	19.2
287	648	592.5	123.0	56.0	.125	.296	1.01	312	66.6	28.9
					Bed Diameter 3.75", Depth 6.46"					
					1/8" Celite Cylinders					
292	648	149.4	120.0	55.5	.688	.023	.56	339	48.8	19.7
296	845	506.4	344.8	53.6	.643	.029	.74	295	46.1	17.5
298	290	218.7	142.8	57.1	.531	.055	.47	129	38.5	13.5
317	1501	205.9	165.6	57.5	.728	.016	.70	662	57.0	23.2
319	1494	405.9	305.1	58.1	.710	.018	.79	554	52.9	21.9
323	788	604.8	396.0	55.2	.620	.033	.79	282	50.1	17.5
325	791	206.9	156.7	54.1	.671	.025	.57	349	46.5	18.8
327	490	252.4	174.0	57.1	.598	.038	.55	208	43.2	15.8
					1/4" Celite Cylinders					
310	491	203.6	135.3	57.8	.531	.055	.87	475	72.3	22.9
311	491	402.9	235.0	58.6	.513	.061	.99	405	68.7	21.6
312	491	498.8	279.2	58.4	.502	.064	1.04	380	67.4	21.2
313	492	586.3	317.8	57.6	.492	.067	1.10	361	67.1	20.9

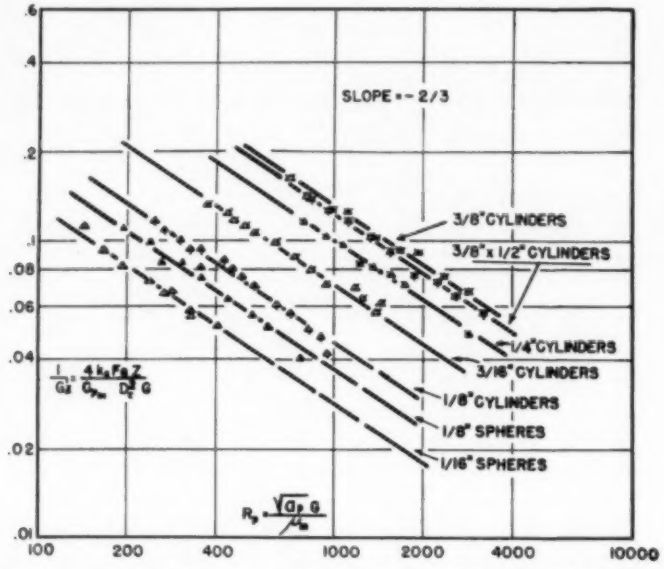

Fig. 5. Reciprocal Graetz number vs. Reynolds number for spherical and cylindrical Celite pellets in a container 2.37 in. in diameter and 6.46 in. in depth. Cooling on convex surfaces.

TABLE 9

SUMMARY OF DATA

Packed Bed 3.75 Inches in Diameter and 12.5 Inches Deep

Run	G	t_0	t_2	t_4	Y	$1/Gz'$	k_e	R_p	$\frac{k_e}{C_{pm}F_s}$	$\frac{1}{Gz}(R_p)^{1/3}$
					1/4" Celite Cylinders					
80	70.0	275.5	76.0	63.3	.080	.425	.53	68	43.1	12.0
85	70.0	140.0	71.3	62.4	.098	.338	.42	75	37.6	12.1
89	70.0	93.3	67.5	60.8	.206	.213	.26	78	24.7	12.5
90	69.9	246.5	74.8	62.1	.069	.400	.50	69	41.3	12.0
94	69.7	458.8	82.1	62.3	.050	.455	.57	61	41.3	11.5
95	162.3	601.8	132.5	62.8	.129	.291	.85	127	55.1	14.7
100	162.5	204.1	88.9	65.8	.167	.251	.72	164	61.1	16.0
105	162.9	166.5	81.4	61.9	.187	.230	.65	169	57.8	16.2
110	286	310.2	126.0	64.5	.250	.176	.89	270	69.2	18.9
115	287	127.1	80.6	61.6	.290	.152	.76	305	69.4	19.7
120	485	598.2	217.3	64.5	.286	.143	1.25	372	78.9	21.0
125	486	200.8	110.4	61.5	.351	.120	1.02	486	86.7	23.0
130	784	625.8	268.9	63.4	.366	.113	1.60	583	97.0	24.5
135	787	259.6	143.4	62.3	.411	.093	1.30	740	102.7	26.5
140	785	106.5	81.6	61.2	.452	.080	1.09	846	100.6	27.7
333	791	208.5	120.5	56.7	.420	.090	1.18	771	99.0	26.9
337	793	618.1	272.9	57.7	.384	.105	1.43	587	87.6	24.5
					3/8" Celite Cylinders					
395	490	362.0	148.9	56.8	.334	.145	1.12	626	88.5	23.8
396	791	299.0	168.0	56.8	.386	.103	1.28	994	99.0	27.7
397	1494	250.4	170.7	57.3	.464	.075	1.77	1876	136.5	34.2
398	2070	312.8	192.0	57.8	.503	.063	2.07	2540	155.0	37.7
					3/16" Celite Cylinders					
399	488	304.8	172.5	57.4	.338	.100	.77	324	69.0	15.4
400	789	297.0	176.1	57.1	.468	.075	.94	491	72.1	18.1
401	1494	302.0	188.5	56.7	.535	.054	1.28	976	103.0	22.8
402	2068	301.7	192.1	57.8	.575	.043	1.42	1342	113.4	25.3
					1/8" Celite Cylinders					
356	491	200.2	125.6	57.7	.476	.072	.54	222	45.5	16.2
360	491	592.8	280.6	58.0	.416	.091	.70	170	43.2	14.8
380	795	203.5	132.7	57.2	.516	.060	.72	355	60.0	18.9
384	797	622.3	317.3	56.6	.461	.075	.94	266	56.5	17.2
385	1509	463.4	283.5	56.3	.558	.046	1.13	549	74.1	21.8
389	1511	148.6	112.0	56.8	.603	.037	.83	714	73.0	23.8
390	2088	160.7	122.1	56.9	.628	.031	.99	972	85.7	26.4
394	2094	384.3	253.2	57.0	.600	.037	1.20	802	83.4	24.8

For a given pellet size the majority of the data lies on straight lines of slope approximately $-\frac{2}{3}$. A relation of the form shown below is indicated:

$$\frac{1}{Gz'} = B(R_p)^{-\frac{2}{3}} \qquad (15)$$

wherein B varies with the size of the pellet (Table 1).

A logarithmic plot of the coefficient, B, vs. the surface area of the pellets, a_p, is shown as Line A in Figure 6. Since the slope is ½ in. it follows that

$$B = b(a_p)^{\frac{1}{2}} \qquad (16)$$

The point representing the data for the large-sized pellets (⅜-in. × ½-in. cylinders) falls considerably below the line. This is thought to be due to the onset of wall effects.

The effect of bed diameter was then investigated by analyzing data taken using beds of virtually the same length but with diameters of 1.37 in. and 3.75 in. Only one size of pellet (⅛-in. cylinders) was used in the smaller bed. Two sizes, ⅛-in. and ¼-in. cylinders, were used in the larger bed. Typical data are shown in Table 8. Results plotted as $1/Gz'$ vs. R_p are shown in Figure 7, Lines A, B, and C. From these lines values of the respective coefficients (or B values) were found as for the previous data. Results are summarized in Table 2. These values of the coefficient are plotted in Figure 6 at the corresponding values of pellet surface area. Lines B and C on this figure were then drawn in with slopes equal to that of Line A, previously established as 0.5. For the smallest contain ϵ, only one point is available, thus this line (Line C) is shown dotted.

Values of coefficient b, appearing in Equation (16), may now be obtained for the three bed diameters. These are tabulated in Table 3.

The relation between the coefficient b and the bed diameter D_e is given in Figure 8. If the point for the large diameter container is neglected a line of slope -2 is obtained. For reasons which will become apparent this was done although the point for the bed of diameter 3.75 in. (0.31 ft.) is about 25% low. Justification of this is based on the observation that for several methods of analyzing the experimental results, data for this bed were always consistently low. With this assumption the relation between b and D_e is found as

$$b = MD_e^{-2} \qquad (17)$$

Finally the influence of depth of bed was investigated. For this purpose data for a bed 3.75 in. in diameter and 12.5 in. in length were used. Plots of these data as $1/Gz'$ vs. R_p are shown in Figure 7 as Lines B, D, E, and F, these lines being obtained from observations using ⅛ in., 3/16-in., ¼-in., and ⅜-in. Celite cylinders, respectively. Typical samples of the data are tabulated in Table 9.

Intercepts of these lines (B values) were plotted in Figure 6 in order to obtain Line D in that figure. From this chart the value of b for the 12.5-in. bed was obtained and plotted on Figure 8. The dotted line is drawn through this point parallel to the line previously established for a bed depth of 6.46 in., i.e., having a slope of −2.0. Displacement of these lines was considered due to the difference in bed depths only, that is, it was assumed that $M = f(Z)$.

Table 4 shows the results of the analysis of Figure 8. These values are plotted in Figure 9. It was observed that the straight line passing through these two points had a slope of 1.0, thus based on these limited data the relation between M and Z becomes

$$M = C'(Z)^1 \qquad (18)$$

Combining Equations (15)-(18)

$$\frac{1}{Gz'} = \frac{4k_e Fe Z}{C_{pm} D_c^2 G} = C'Z \cdot (D_c)^{-2} (a_p)^{1/3} (R_p)^{-2/3} \qquad (19)$$

Combining the constant, 4, with C', and rearranging, and dividing both sides by μ_m,

$$\frac{k_e}{C_{pm}\mu_m} = \frac{(C)}{(Fe)} \frac{(a_p^{1/6} G^{1/3})}{(\mu_m^{1/3})} = \frac{(C)}{(Fe)} (R_p)^{1/3} \qquad (20)$$

The group, $C_{pm}\mu_m/k_e$, may be called a modified Prandtl group, Pr', wherein the over-all effective conductivity of the dynamic system is used instead of the conductivity of the fluid.

In order to note the range of the data and the deviations from the relation shown as Equation (20) and to obtain an average value for the coefficient, C, a rectangular plot, Figure 10, was made. The best line through the data has a slope of approximately 3.7 thus giving as the final correlation

$$\frac{k_e}{C_{pm}\mu_m} = \frac{3.7}{Fe} \left(\frac{\sqrt{a_p} G}{\mu_m} \right)^{1/3} \qquad (21)$$

or

$$\frac{1}{Pr'} = \frac{3.7}{Fe} (R_p)^{1/3} \qquad (22)$$

Since for air the group $C_{pm}\mu_m/k_e$ is approximately equal to 0.74, Equation (21) may be written

$$\frac{k_e}{k_g} = \frac{2.74}{Fe} \left(\frac{\sqrt{a_p} G}{\mu_m} \right)^{1/3} \qquad (23)$$

Discussion

The use of this correlation for cases where the Reynolds group is much less than those used in its development is not recommended since it is felt that additional variables must be taken into consideration under such circumstances.

Several observations concerning the deviation of some data from the generalized correlation appear significant. Most values for the 1/16-in. Celite

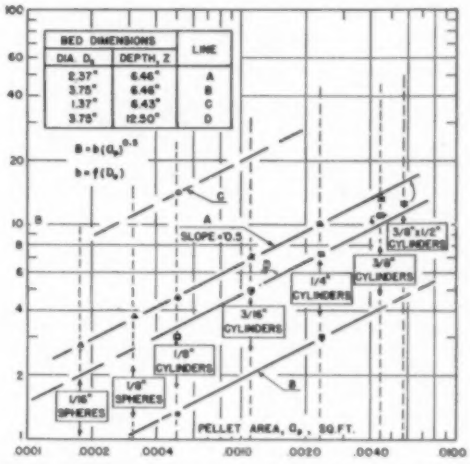

Fig. 6. Values of "B" vs. surface area of pellets for beds of various dimensions.

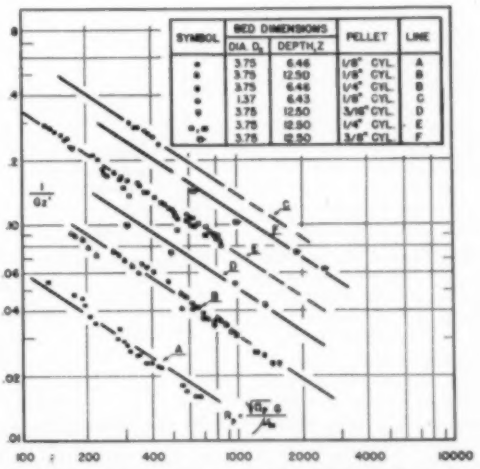

Fig. 7. Reciprocal Graetz number vs. Reynolds number for cylindrical Celite pellets in containers of various dimensions. Cooling on convex surfaces.

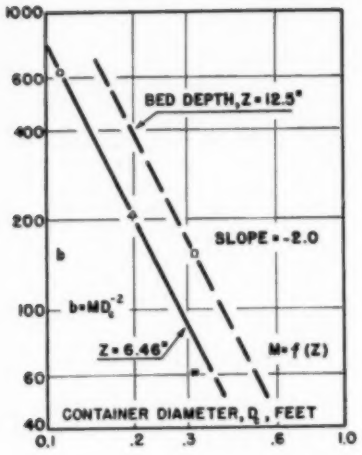

Fig. 8. Values of "b" vs. diameter of container for two different bed depths.

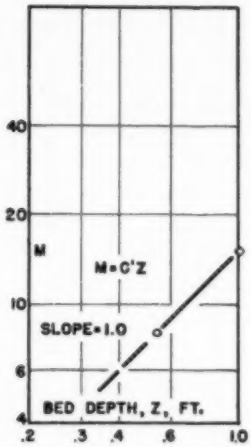

Fig. 9. Values of "M" vs. bed depth.

spheres lie above the line by approximately 10%. No explanation is offered for this although it may arise from an error in the method of measuring the void fraction of the spheres. As mentioned previously, the values obtained in the short bed of largest diameter were consistently low. It is believed that entry and exit effects are responsible for this, the influence of which becomes of smaller importance as the ratio of length to diameter increases.

Of greater significance, however, is the rapid diminution in the effective conductivity as the radial temperature gradient is reduced below a critical value. The situation which was observed at low mass velocities using ¼-in. Celite cylinders in a container 3.75 in. in diameter and 12.5 in. deep will be considered. With a mass velocity of 70 lb./(hr.)(sq.ft.) values of k_e diminished rapidly as the average radial temperature difference is reduced below 50° F.; this temperature difference, Δt, being the difference between the arithmetic average gas temperature and the surface temperature. At a mass velocity of 163 lb./(hr.)(sq.ft.) the critical Δt is reduced to about 25° F. These results are indicated in Figure 10. As the mass velocity is increased the critical temperature difference diminishes rapidly so that at a mass velocity of 1500 no rapid diminution in k_e is noted until this temperature difference is reduced to perhaps 10° F., for the above system. The point at which this phenomenon becomes evident would also depend upon the length-to-diameter ratio of the bed as well as the size and nature of the solid material.

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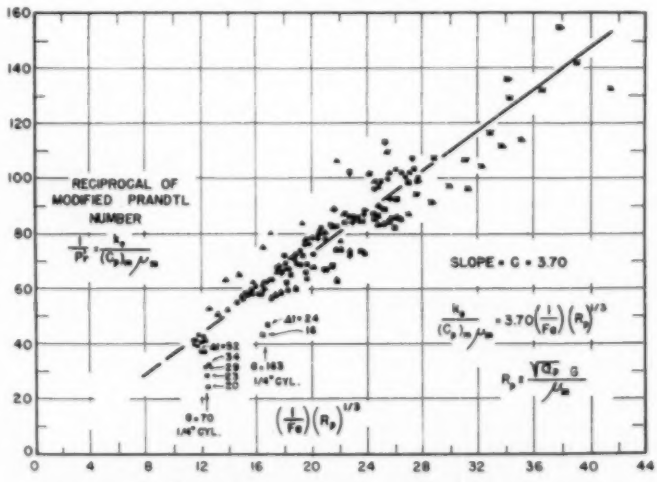

Fig. 10. Plot of original data as reciprocal of modified Prandtl group vs. $(1/Fe)\,(R_p)^{1/3}$ for various sizes and shapes of Celite pellets in beds of different dimensions. Air being cooled during downward flow.

periment Station of the University of Minnesota prepared the manuscript.

The many invaluable contributions by those who prefer to remain in anonymity are also greatly appreciated.

Notation

a = radius of cylinder or bed of granular material, ft.

a_p = surface area of a pellet, sq.ft.

$b,B,C'C$ = coefficients used in analysis of data

C_p = heat capacity at constant pressure, B.t.u./(lb.)(° F.)

C_{pm} = heat capacity at temperature t_m

D_c = diameter of cylindrical container in which the granular material was supported, ft.

e = base of natural logarithms, 2.7183

E = unaccomplished temperature change defined such that $E = t_a - t_s/t_o - t_s$

f = indicates "function of"

Fe = fractional void space in bed of granular material

G = mass velocity of fluid, lb./(hr.)(sq.ft.)

Gz' = modified Graetz number $C_{pm}D_c^2G/4k_eFeZ$

$J_o(x)$,

$J_1(x)$ = Bessel functions of zeroth and first order, respectively

k = thermal conductivity, B.t.u./(hr.)(sq.ft.)(° F./ft.)

k_e = effective thermal conductivity of heterogeneous gas-solid system

k_g = thermal conductivity of a gas

K = thermal diffusivity, k_e/C_{pp}

M = coefficient used in analysis of data

Pr' = modified Prandtl number, $C_{pm}\mu_m/k_e$

Q = quantity of heat energy, B.t.u.

r = radial distance of a point in a cylinder from the axis, ft.

R_p = modified Reynolds number, $\frac{\sqrt{a_p}G}{\mu_m}$

t_a = average temperature of effluent gas, ° F.

t_m = arithmetic mean temperature of the gas, $t_a + t_o/2$

t_o = average temperature of inlet gas

t_s = average surface temperature

Δt = average radial temperature difference, $t_m - t_s$

w = mass rate of flow, lb./hr.

Z = depth of bed of granular solids, ft.

α_i = ith root of Bessel function of zeroth order

θ = time, hrs.

μ_m = viscosity of gas at temperature t_m, lb./(ft.)(hr.)

ρ = density, lb./cu.ft.

ρ_{ave} = average density

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SALT EFFECT IN VAPOR-LIQUID EQUILIBRIA

Ethanol-Water Saturated with Inorganic Salts

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The effect of inorganic salts on the vapor-liquid equilibrium of the ethanol-water system at one atmosphere pressure was studied using saturated solutions of sodium sulfate, potassium sulfate and sodium nitrate. Calculated values of relative volatilities and activity coefficients are presented, and their significance discussed. A correlation expressing the increased ease of separation as a function of salt solubility is presented. The van Laar equations were found to fit the data for the ethanol-water-sodium sulfate system more closely than the Margules equations. The occurrence and importance of such salt systems are briefly reviewed.

A PROGRAM to investigate the effect of dissolved salts on the vapor-liquid equilibrium of a binary system, which was stated in a previous paper (*9*), has been continued.

Three component systems consisting of two liquids and one salt have been encountered in various industrial processes. For example, in the crystallization of inorganic salts by means of organic solvents such as ethanol (*6, 10*), a liquid phase results which consists of the two liquid components saturated with the salt. Because of economic considerations, the ethanol must be recovered for recycling back to the crystallizer. Also in many organic processes, an intermediate compound is subjected to either an alkali or acid hydrolysis resulting in an organic-water-salt mixture from which the valuable organic product must be separated. Such is the case in the manufacture of synthetic phenol (*2*) and synthetic glycerol (*15*). In the former, sodium phenate, an intermediate, is treated with hydrochloric acid in order to release the phenol, while in the latter the glycerol is released from the chlorohydroxy intermediate by an alkali hydrolysis. In both cases a mixture of water-sodium chloride-organic product results.

In many such cases distillation affords the most economical means of recovering or separating the liquid components. In the design of the distillation equipment, the vapor-liquid equilibrium relationship between the two components is of prime importance, consequently, any factors affecting the equilibrium relationship will in turn affect design. The presence of salt is such a factor (*2, 7, 9*) which at present must be evaluated experimentally. It is hoped, however, that as more data accumulate, a correlation may result which will make it possible to predict the salt effect in those cases for which data are not available.

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TABLE 1.—SUMMARY OF VAPOR-LIQUID EQUILIBRIUM DATA WITH SALT AS A THIRD COMPONENT AT ONE ATMOSPHERE

System A-B	Salt	Comp. Range Mole % A (Salt-free liquid)	Salt Conc.	Investigators
Phenol-Water *	NaCl	0–6	0–17 wt. %	Bogart & Brunjes (*2*)
Ethylene Glycol-Water	Na_2SO_4	0–100	saturated	Fox (*4*)
Ethanol-Water	NaOR R = Alkyl or Aryl group	82–98	saturated	Kyrides & co-workers (*7*)
Ethanol-Water	K_2CO_3	80–90	saturated	Kyrides & co-workers (*7*)
Ethanol-Water	KNO_3	0–100	saturated	Rieder & Thompson (*9*)
Ethanol-Water	Na_2SO_4	0–100	saturated	Authors
Ethanol-Water	K_2SO_4	8–20	saturated	Authors
Ethanol-Water	$NaNO_3$	8–20	saturated	Authors
Acetic Acid-Water	$CaCl_2$	0–100	0–saturated	Garwin & Hutchison (*5*)

* Data at 1 and 4 atm.

An investigation of this type can be made on many systems with varying solubility characteristics of the salt and solvent properties of the liquid. Systems in which (a) salt is relatively soluble only in the low boiling component, (b) salt is relatively soluble only in the high boiling component, (c) salt is soluble in both components, would each require a separate type of experimental study. Much of the work done to date giving information of this sort over a wide solvent composition range, and with an appreciable amount of salt present, is summarized in Table 1. Results of these investigations suggest that the salt may be looked upon as a third component, in a manner analogous to that of a liquid third component commonly used in azeotropic and extractive distillation. Many of the useful theoretical and practical generalizations made for liquid third components apply very well in explaining the salt effect. Their function is to increase the nonideality of the binary system which in many cases results in a greater ease of separation.

In the present work, the vapor-liquid equilibria were investigated for aqueous solutions of ethanol saturated with sodium sulfate, sodium nitrate or potassium sulfate. The latter two salts were studied only over the range of solvent compositions in which the greatest salt effect was expected to occur. The system ethanol-water was chosen as it had been used in a preliminary study of the salt effect (*9*). The first salt (sodium sulfate) was chosen because saturated density data for a large range of compositions were available (*12*), and this provided a simple means of analysis. Also this salt has a much lower solubility in water than potassium nitrate previously studied (*9*). The other two salts were selected to see what effect, if any, different combinations of the two anions and the two cations would have.

Experimental Equipment and Measurements. The equilibrium still was a Pyrex

glass-Othmer type, slightly modified as shown in Figure 1. A stoppered ground-glass joint was built into the wall of the stillpot to provide an opening for the addition of salt. The vent line, provided at the top of the vapor condensate return, aided in sample removal. The still was heated with an electric radiant heater placed underneath. The walls were kept above the boiling temperature by nichrome wire embedded in the sheet lagging on both the stillpot and the upper section. The heat input to the upper heating coil was regulated so that overhead vapors were superheated about 10° to 15° C. above the boiling temperature of the liquid in order to prevent refluxing along glass surfaces.

The charging, operation and sampling of the still were fully described in a previous paper (9). In the present work, use of the salt feed port simplified the charging procedure. All runs were made at atmospheric pressure which varied 760± 10 mm.

The ethanol contents of both vapor condensate and liquid residue samples were obtained by density measurements made at 25° C. for the pure ethanol-water solutions and at 35° C. for the saturated salt solutions. Calibrated 5-g. and 10-g. capped Gay-Lussac specific gravity bottles were used in these measurements. By means of the tables of density-composition data found in Perry (8), the compositions of the vapor condensate samples were obtained. The density-composition data of Vener and Thompson (12) at 35° C. for saturated solutions of sodium sulfate were plotted on a large graph and used to determine the ethanol content of the residue samples on a salt-free basis. As similar data did not exist for the other two salts (sodium nitrate and potassium sulfate) they were experimentally determined in this work. Three known ethanol-water solutions of 20, 30 and 40 wt. % were saturated with vacuum-dried salt and brought to equilibrium in a constant temperature bath. Densities of the saturated solutions were measured and plotted against the ethanol composition of the salt-free solution. In this form the data were used for the analysis of the residue still samples. The precision of vapor-liquid compositions obtained in this manner was found to be ±0.05% in the vapor phase and ±0.1% in the liquid phase.

Boiling-point data were obtained by means of a 2000-ml. three-necked flask almost filled with saturated salt solution boiling under total reflux. Baker and Waite (1) attempted to use a Cottrell-type boiler for accurate determinations of boiling points but were unsuccessful due to salt plugging the arms of the pump. The boiling points were corrected for changes in atmospheric pressure and emergent thermometer stem. The precision of the temperature measurement was about ±0.1° C.

Treatment of Equilibrium Data. The experimental equilibrium data for all three salts are listed in Table 2 and plotted as a $y - x$ diagram in Figure 2. From this plot, it is to be noted that the presence of dissolved salts enhances the degree of separation between ethanol and water. In addition, the more soluble salts, sodium nitrate and potassium nitrate, have a greater effect than the less soluble ones, sodium sulfate and potassium sulfate. The boiling-point determinations, presented in Table 3, were used in the calculation of activity coefficients.

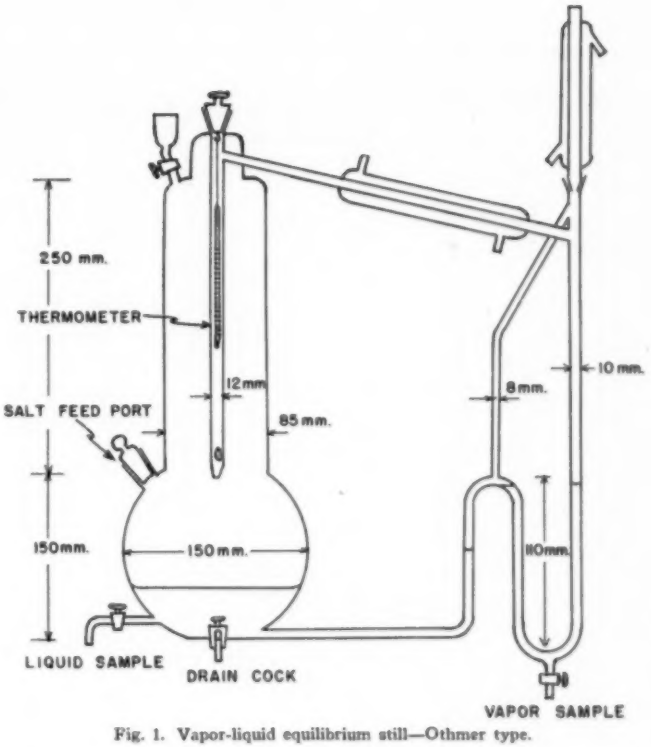

Fig. 1. Vapor-liquid equilibrium still—Othmer type.

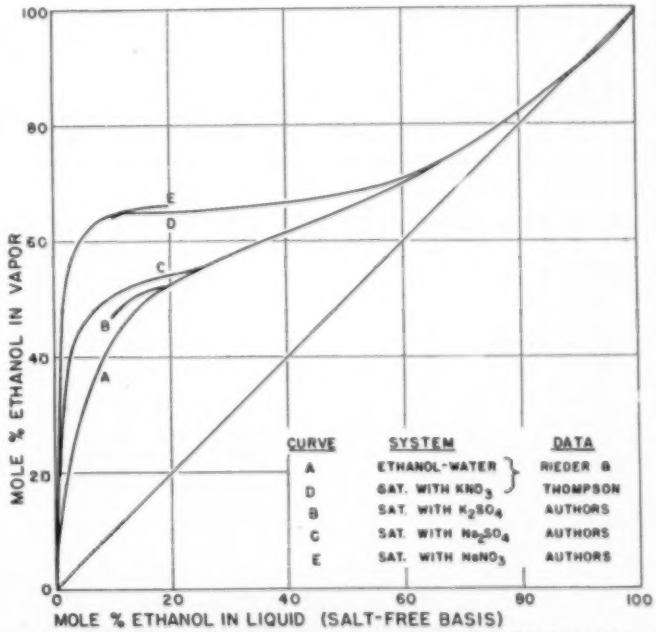

Fig. 2. Vapor-liquid equilibrium data for ethanol-water saturated with various inorganic salts at atmospheric pressure.

TABLE 2

Summarized Results for Ethanol-Water Solutions Saturated with Salts

Wt. % Ethanol		Mole % Ethanol		B.P.	Activity Coefficients		Relative
X*	Y	x*	y	°C	Ethanol	Water	Volatility
			Sodium Sulfate				
1.0	24.6	0.4	11.3	100.6	12.3	0.87	31.7
1.5	35.8	0.6	17.9	99.5	13.6	0.84	36.1
3.0	44.9	1.2	23.4	95.2	10.4	0.92	25.1
4.2	48.9	1.7	26.8	92.8	9.1	0.97	21.1
4.7	51.6	1.9	31.1	91.9	9.8	0.95	23.3
6.3	62.6	2.6	39.6	88.8	10.1	0.94	24.5
9.6	67.4	4.0	44.7	85.5	8.4	0.99	19.4
14.8	70.2	6.8	48.0	83.9	5.6	1.02	12.7
22.4	72.1	10.1	50.3	83.4	4.1	1.03	9.0
28.2	73.7	13.3	52.3	83.0	3.3	1.04	7.2
28.5	74.1	13.5	52.8	83.0	3.2	1.03	7.2
30.6	74.9	14.6	52.6	82.8	2.96	1.06	6.3
35.6	76.7	17.8	53.6	82.6	2.64	1.09	5.3
36.0	76.6	18.0	53.5	82.5	2.51	1.10	5.2
40.0	78.0	20.7	53.5	82.3	2.20	1.14	4.4
41.9	78.7	22.0	53.6	82.3	2.07	1.16	4.1
44.9	79.6	24.9	54.8	82.0	1.89	1.19	3.7
46.2	79.4	25.1	55.9	82.0	1.92	1.16	3.8
47.5	79.6	26.1	56.1	81.9	1.86	1.18	3.6
50.3	79.9	28.4	56.6	81.7	1.73	1.21	3.3
51.1	77.0	29.0	56.7	81.6	1.71	1.22	3.2
52.5	77.4	30.2	57.2	81.6	1.66	1.23	3.1
59.7	78.8	36.7	59.3	81.0	1.45	1.32	2.5
59.9	79.0	36.8	59.6	81.0	1.45	1.31	2.5
69.6	82.0	46.8	64.1	80.3	1.26	1.43	2.0
70.1	82.0	47.8	64.1	80.2	1.24	1.46	1.9
76.2	84.3	55.6	67.8	79.8	1.15	1.55	1.7
87.1	88.9	72.5	75.6	78.9	1.02	1.97	1.2
88.0	89.9	74.2	77.8	78.8	1.03	1.93	1.2
90.3	90.7	78.4	79.2	78.7	1.00	2.17	1.05
			Potassium Sulfate				
22.0	69.2	10.0	46.8	84.6	3.65	1.05	7.9
31.5	73.3	15.3	51.7	83.6	2.74	1.06	5.9
36.5	75.0	18.4	51.5	82.7	2.34	1.14	4.7
			Sodium Nitrate				
19.2	61.6	6.5	63.6	80.6	6.92	0.83	18.9
20.9	62.5	10.4	64.8	80.7	5.65	0.82	15.9
37.3	69.3	18.9	66.2	80.6	3.19	0.87	8.4

* Liquid compositions on a salt-free basis.

The calculated relative volatilities and activity coefficients are listed in Table 2, and plotted in Figures 3 and 4 respectively. For the purpose of comparison, curves for pure ethanol-water and ethanol-water saturated with potassium nitrate are included.

Relative volatility is the most important factor in indicating the ease of separation of components by distillation.

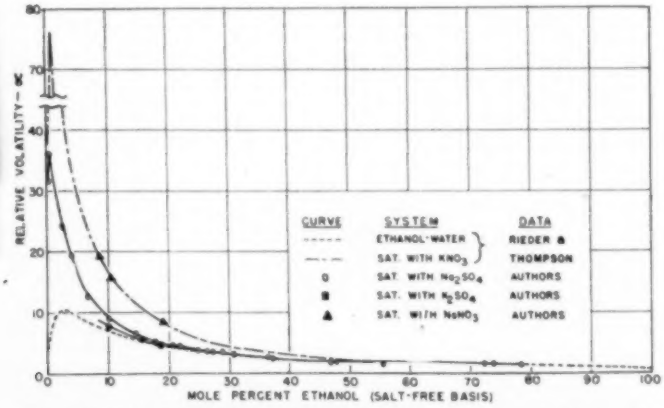

Fig. 3. Relative volatilities for ethanol-water saturated with various inorganic salts at atmospheric pressure.

the higher the value, the greater the ease of separation. As it is expressed as a ratio of volatilities of the two components, the presence of any third component which tends to increase the difference in these volatilities, will in effect increase the relative volatility. The increase in relative volatility varies with each salt and each ethanol-water composition as is shown in Figure 3. As the rise in relative volatility appears to be due to the solubility of the salt, and as the salt is relatively soluble in only the water component of the ethanol-water system, the molal solubility of each salt in water at the boiling point of the saturated solution was considered as a correlating variable. The resulting correlation is shown as a log-log plot in Figure 5. The solubility of each salt in pure water at 80° C. was chosen as the actual boiling points varied only between 80° and 84° C. for the composition range plotted. The fact that the slope of these lines is close to unity suggests that the increase in relative volatility is not a power function of the solubility of the salt in water. As an approximation, assuming a slope of unity, the equation of the lines shown may be written in the form:

$$\log (\Delta\alpha) = \log S + \log K \qquad (1)$$

or

$$\Delta\alpha = KS \qquad (2)$$

(a straight line through the origin on a regular coordinate plot)

Where

$\Delta\alpha$ = the increase in relative volatility

S = moles of salt/mole of water at saturation

From Figure 5, at $S = 1$:

$K = 40$ for the 20 wt. % ethanol composition

$K = 18$ for the 30 wt. % ethanol composition

This relationship agrees with the known fact that with no salt present ($S = 0$) $\Delta\alpha$ should be equal to zero. Then, for the range covered for the four salts, the increase in relative volatility is approximately proportional to the molal solubility of the salt in water at the boiling point of the solution. This substantiates the general statement of Updike and co-workers (*11*) that the solubility at the boiling point is the most obvious qualitative basis with which the effectiveness of a third component may be related.

The concept of activity coefficient (*3*) has found widespread use for expressing the nonideality of a system and in checking the accuracy of vapor-liquid

equilibrium data. As used here, as well as by many other authors, the activity coefficient is really a Raoult's law deviation factor for the calculation of which the vapor is assumed to behave as an ideal gas. The deviation factor for component 1 is calculated from:

$$\gamma_1 = \frac{Py_1}{P_1 x_1} \qquad (3)$$

where

P = total pressure
P_1 = vapor pressure of component 1 at the given temperature (same units as P)
y_1 = mole fraction of component 1 in the vapor
x_1 = mole fraction of component 1 in the liquid

For systems having positive deviations, such deviations from unity in activity coefficient values increase as the nonideality of a system increases. Values of the activity coefficients for water plotted in Figure 4 were calculated using the vapor pressure of water at each temperature as indicated in the equation given above. Bogart and Brunjes (*2*) instead used the vapor pressure of salt-water solutions and obtained values in the high water compositions which were at no time less than one. A number of activity coefficients were recalculated using their method, i.e., by taking into account the lowering of the water vapor pressure.

Equations expressing the activity coefficients of both components of a binary mixture as functions of the liquid compositions and empirical constants are presented by Carlson and Colburn (*3*). Such equations, as given below, may be used to examine the accuracy or extend the use of experimental data. Only the two volatile components, ethanol and water, were considered in applying the equations to the system involved in this work.

van Laar equations

$$\log \gamma_1 = \frac{A}{\left(1 + \frac{Ax_1}{Bx_2}\right)^2} \qquad (4)$$

$$\log \gamma_2 = \frac{B}{\left(1 + \frac{Bx_2}{Ax_1}\right)^2} \qquad (5)$$

Margules equations

$$\log \gamma_1 = (2B - A)x_2^2 + 2(A - B)x_2^3 \qquad (6)$$

$$\log \gamma_2 = (2A - B)x_1^2 + 2(B - A)x_1^3 \qquad (7)$$

where

γ_1, γ_2 = activity coefficients of ethanol and water respectively

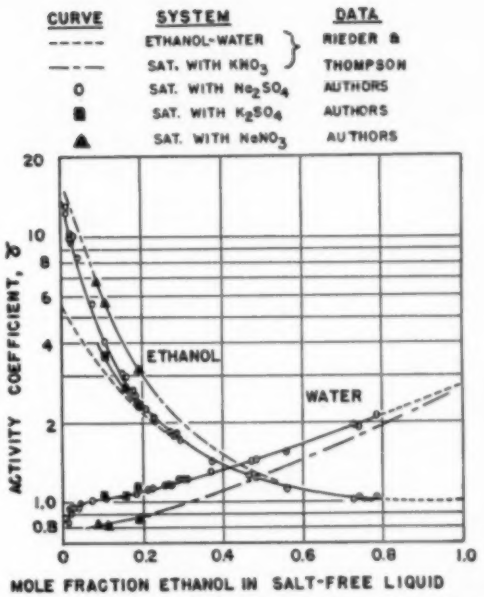

Fig. 4. Activity coefficients for ethanol-water saturated with various inorganic salts at atmospheric pressure.

x_1, x_2 = liquid mole fractions of ethanol and water respectively
$A = \log \gamma_1$, at $x_1 = 0$
$B = \log \gamma_2$, at $x_1 = 1$ or $x_2 = 0$

According to the observations outlined by Carlson and Colburn (*3*), the van Laar equations should apply to the ethanol-water-sodium sulfate system more closely than the Margules equations. Accurate values of the A and B constants were obtained as suggested by White (*14*) as well as by extrapolation of the usual activity coefficient plot. In the application of White's method, the A and B constants were obtained from the slope and intercept of the straight line

TABLE 3

Boiling Points at Atmospheric Pressure for Ethanol-Water Solutions Saturated with Salt

Wt. % Ethanol (Salt Free)	Corrected Temp. °C.	Wt. % Ethanol (Salt Free)	Corrected Temp. °C.
	Na_2SO_4		
0.0	103.0	32.8	82.4
1.9	99.6	33.6	82.5
2.8	94.6	34.7	82.4
2.9	95.6	41.2	82.4
4.8	91.9	43.5	82.0
6.0	89.4	43.9	82.1
8.0	86.2	56.1	81.4
9.2	85.5	62.5	80.9
12.0	84.3	69.8	80.3
16.7	83.9	76.7	79.9
20.3	83.7	85.1	79.4
25.8	83.3	90.9	78.7
	K_2SO_4		$NaNO_3$
22.0	84.6	19.2	80.6
31.5	83.6	22.9	80.7
36.5	82.7	37.3	80.6

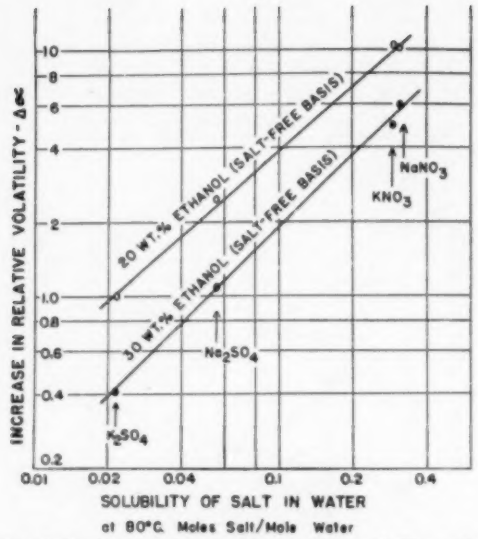

Fig. 5. Correlation between the increase in relative volatility and solubility of salt in water.

resulting when the experimental activity coefficients were plotted according to a rearranged form of the van Laar equation:

$$\frac{1}{\sqrt{\log \gamma_1}} = \frac{\sqrt{A}}{B}\left(\frac{x_1}{x_2}\right) + \frac{1}{\sqrt{A}} \qquad (8)$$

The A and B values were found to be 1.13 and 0.36 respectively. Comparison of the calculated with the experimental values of the activity coefficients shown in Table 4 indicates that the van Laar equations represent the data closely. Activity coefficients calculated from the Margules equations using the above A and B values were found to be closer to the experimental values than those obtained from the extrapolated A and B values.

Discussion and Application of Salt-Effect Data. It can be concluded from the results of this investigation that: (a) the addition of a salt which is relatively soluble only in the high boiling component will cause a greater ease of separation between the components of a binary mixture, and (b) the ease of separation increases as the solubility of the salt in the high boiling component increases. These results are in agreement with the statement (*13*) that the addition of a material very soluble in one component of a mixture but not in the other will lower the vapor pressure of the component in which it is soluble but will not appreciably affect the vapor pressure of the other, thus increasing the ease of separation.

TABLE 4.—ACTIVITY COEFFICIENTS

Ethanol-Water Saturated with Sodium Sulfate

Liquid Composition Mole % Ethanol	Experimental	van Laar	Margules
		$A = 1.13$ $B = 0.36$	
	Ethanol		
20	2.26	2.26	3.36
50	1.30	1.17	1.39
80	1.00	1.01	0.99
	Water		
20	1.12	1.17	1.16
50	1.50	1.61	1.91
80	2.2	2.1	2.7

The relative volatility values indicate that the ease of separation increases as the nonideality of the system increases. Concerning this, Bogart and Brunjes (*2*) stated that the nonideality of binary mixtures increases with decreasing mutual solubilities of the two components, and that the addition of nonvolatile solids to these mixtures enhances the relative volatility of the components by increasing their relative deviation from ideal solution laws through a further decrease in mutual solubility. It is not surprising, therefore, that Rieder and Thompson (*9*) observed two liquid phases in the case of potassium nitrate over a wide range of compositions, whereas the authors observed only a single liquid phase throughout the entire composition range in the case of the less soluble sodium sulfate. These observations are in agreement with the fact that the ethanol-water system saturated with potassium nitrate had higher relative volatilities and ethanol activity coefficients than that saturated with sodium sulfate.

It was not possible to break the ethanol-water azeotrope either with potassium nitrate, as used by Rieder and Thompson (*9*), or with potassium carbonate, as employed by Kyrides and coworkers (*7*). However, the latter were successful when using some salts of the type NaOR, KOR and CaOR (where R was either an alkyl or aryl radical) in a packed column.

Data similar to those obtained in this investigation were used (*2*) to design a plant for the recovery of phenol from a phenol-water-sodium chloride mixture by distillation under pressure. Kyrides and co-workers (*7*) also suggested a large-scale packed column in which salts are added at some optimum point near the top in order to obtain anhydrous ethanol. This type of operation requires the continuous cycling of salt and its continuous recovery from the liquid residue stream.

As distillation possesses many favorable engineering aspects as a unit operation, processes such as extractive distillation have been developed to overcome the difficulty of low relative volatilities. For similar reasons, the addition of inorganic salts to some systems involving water and an organic compound warrants further consideration from an economic standpoint.

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HEAT TRANSFER BY DIRECT CONTACT BETWEEN LIQUID AND VAPOR

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Actual performance data of plant equipment cooling hot C_4 gases by direct contact with a distillate oil have been correlated, and the results used to provide a comparison of the relative effectiveness of three separate types of contacting equipment. The system studied includes a conflow downward empty spray tower, and a counterflow tower with disc-and-doughnut baffles in one section and perforated side-to-side baffles in another section. Results show that the spray tower is more effective than the disc-and doughnut section over the entire range studied and that the side-to-side baffles are more effective than either of the other sections at high vapor and low liquid rates but are about equal to disc-and-doughnut baffles at low vapor and high liquid rates. It is concluded that the particular arrangement studied is advantageous where rapid cooling of a vapor under low pressure is of prime importance.

THIS paper presents information derived from the commercial operation of a quench system utilizing direct contact between vapor and liquid phases to obtain vapor cooling. From basic performance data, concepts have been developed which should be of value in the design of similar equipment. Nearly all previous work pertaining to vapor-liquid contacting is concerned with the phenomenon of mass transfer while that of heat transfer is neglected or subordinated. Nevertheless, there are seemingly good reasons for choosing such a process for the prime objective of heat transfer, as for instance in the present case, where a gaseous stream at high temperatures and low pressure must be cooled swiftly to prevent degradation as a result of undesirable chemical reactions.

Data for this study were obtained from the operation of the quench system cooling vapor phase effluent from the catalytic dehydrogenation reactors in the butadiene plant at El Segundo, Calif. This plant is operated by Standard Oil Company of California acting as agent for the Office of Rubber Reserve, Reconstruction Finance Corp. Calculation methods and correlations have been developed based upon an enthalpy difference driving force which permit comparing the effectiveness of three separate types of contacting equipment. Quantitative data show that the use of a conflow spray-quenching tower for initial cooling of the vapor is of distinct advantage and that perforated side-to-side baffles normally provide greater heat exchange than disc-and-doughnut baffles in subsequent countercurrent operation.

Description of Quench System

The equipment studied consists of a conflow spray-quenching stage followed by two stages of countercurrent contacting. The conflow column contains no packing; the countercurrent stages consist of one section of disc-and-doughnut baffles and another of

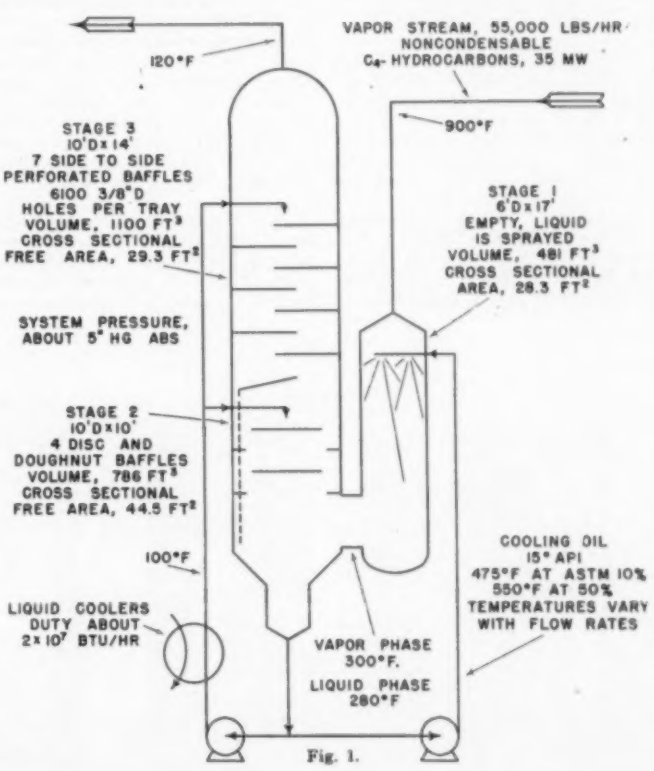

Fig. 1.

TABLE 1.—AVERAGE COMPOSITION OF INLET VAPOR

	Mole %
H_2	34.6
N_2	1.2
CO	1.6
CO_2	1.2
CH_4	2.1
C_2H_4	0.9
C_2H_6	0.6
C_3H_6	1.1
C_3H_8	0.2
C_4H_8	7.5
C_4H_8	22.0
C_4H_{10}	25.2
C_5's	0.1
H_2O	1.7
	100.0

rain decks built into a single column. Figure 1 illustrates the flow and typical conditions at the important locations.

The vapor which is being cooled is the effluent stream from catalytic reactors and contains mixed hydrocarbons, predominantly *C-4's* and lighter. An average analysis of the gas is shown in Table 1. The cooling liquid is a petroleum oil, having typical A.S.T.M. distillation temperatures of 475° F. initial and 550° F. at 50% distilled. Direct quenching of this stream was chosen to give rapid cooling, to have a low pressure drop, and to avoid fouling that would be expected in equivalent indirect heat-exchange equipment.

Based upon several representative measurements, a pressure drop through the quench columns of 2 in. of Hg. and an absolute pressure at the vapor outlet of 5 in. of Hg. was assumed for all cases. The quench oil reaches temperatures at which its vaporization under this low pressure is appreciable.

Stage 1. Initial quenching of the hot inlet vapor is achieved in stage 1, an empty column 6 ft. in diameter by 17 ft. tall in which the gases flow downward through a conflow spray of liquid. Vapor temperatures are lowered from about 900° F. to 300° F. by the heating and vaporization of the oil. The oil is taken from the warm oil stream circulating to the coolers at about 250° F. and is heated in this stage to about 280° F. with perhaps 10-15% of it vaporizing. About 55,000 lb./hr. of vapor flows to this stage and oil rates during test periods varied from 150,000 to 550,000 lb./hr. Duties in this section average approximately 20,000,000 B.t.u./hr., the efficiency being high evidently as a result of high vapor velocities (more than 250 ft./sec. in the 40-in. inlet line and about 60 ft./sec. at the lower part of this column).

Stage 2. The lower part of the second column comprises stage 2 of this vapor-quenching system. Because the oil from the upper section flows in its own downpipe to the bottom of the column, it does not enter into the operation of the lower section. The column is 10 ft. in diameter and an effective height of approximately 10 ft. is involved. Two disc baffles 6 ft. 6 in. in diameter and 2 doughnut baffles whose center opening is 7 ft. 6 in. provide additional contacting surface. Condensation of some of the quench oil vaporized in Stage 1 and further cooling of the vapor to about 200° F. takes place in Stage 2. With oil rates of from 200,000 to 500,000 lb./hr., the oil temperatures are typically near 100° F. in, and 250° F. out, and duties are about 12,000,000 B.t.u./hr. Vapor mass rates typically are about 2,000 lb./(hr.)(sq. ft.) free area, which is reasonably close to the normal vapor rate for similar fractionating columns. The effectiveness of this section, as shown later, is lower than that of Stage 1, presumably because of lower vapor velocities; and ordinarily is lower than that of Stage 3, probably because of less effective contacting afforded by disc-and-doughnut trays compared with rain decks.

Stage 3. Stage 3, in the top of the second column comprises 7 perforated side-to-side baffles covering a height of about 14 ft. Each baffle extends 1 ft. beyond the center of the column for a total overlap of 2 ft. The overlapping area is perforated with ¾-in. diameter holes on ¾-in. triangular centers. As mentioned above, the oil out of this section is by-passed to the column bottom so that it does not affect the operation of stage 2. Stage 3 has typical liquid rates up to 150,000 lb./hr. And duties of 3-8,000,000 B.t.u./hr. including condensation of any remaining vaporized Stage 1 oil. Vapor mass rates are about 2,000 lb./(hr.)(sq.ft.) free area, which is in the normal design range for such columns. The effectiveness of this section is shown to be more critical of vapor and liquid rates than the other stages; in particular, a rather sharp decline in performance results from increasing the liquid traffic above the lowest rates studied.

Data and Calculations

The data available for each test consisted of the orifice meter readings of the three liquid rates and of other process flows sufficient to fix the vapor inlet rate, thermocouple readings of most temperatures, and the A.P.I. gravity and A.S.T.M. distillation of the oil. In addition, mercury manometer readings of the vapor outlet pressure are available for some of the tests, but this pressure is relatively constant (±0.5 in. Hg.) and was assumed for all cases to be 5 in. Hg. abs. From previous tests the pressure drop through the system is known to be 2 in. Hg. Similarly, the inlet gas composition is known to be fairly constant and the average of several analyses was used for all the calculations (*see* Table 1). The temperature of oil from stage 2 was determined from a heat balance.

Heat and material balances accounted for the largest part of the calculation work that was necessary. But the completion of these balances as well as the determination of driving-force potentials depended upon the relation between temperature and the phase equilibrium of noncondensable vapor and partially vaporized oil. This in turn was worked out through a series of equilibrium flash vaporization curves at different pressures derived from the A.S.T.M. distillation of the oil together with an esti-

TABLE 2.—TABULAR

Test No.	Rates, lb./hr.				Liquid Inspections			Vapor Temperatures, ° F.		
	Inlet Vapor	Liquid to Stage 1	Liquid to Stage 2	Liquid to Stage 3	API Gravity	ASTM Dist. Temps., ° F. 10%	50%	Stage 1 Inlet*	Stage 2 Inlet	Stage 3 Inlet
1	44,480	573,000	368,000	120,000	12.0	478	552	760	268	151
2	44,480	573,000	402,000	108,000	12.0	478	552	760	265	144
3	44,480	568,000	440,000	53,900	12.0	478	552	760	267	140
4	44,480	577,000	374,000	71,800	12.0	478	552	760	270	153
5	44,480	587,000	333,000	71,800	12.0	478	552	760	273	155
6	44,480	587,000	299,000	71,800	12.0	478	552	760	277	160
7	44,480	587,000	261,000	71,800	12.0	478	552	760	285	168
8	44,480	587,000	218,000	71,800	12.0	478	552	760	290	176
9	44,480	587,000	172,000	144,000	12.0	478	552	760	290	190
10	44,480	560,000	115,000	215,000	12.0	478	552	760	289	205
11	44,480	560,000	86,200	302,000	12.0	478	552	760	280	205
12	44,480	565,000	0	323,000	12.0	478	552	760	295	212
13	45,510	443,000	372,000	91,200	26.4	480	500	800	280	167
14	54,110	378,000	420,000	56,000	14.8	478	566	870	307	158
15	54,110	*162,000	?*0,000	122,000	14.8	478	566	850	333	182
16	54,110	*137,000	382,000	123,000	14.8	478	566	800	335	190
17	54,660	362,000	320,000	97,300	36.0	468	483	880	305	217
18	54,910	282,000	274,000	145,000	14.8	483	559	770	308	164
19	55,760	256,000	284,000	121,000	13.8	486	552	800	342	206
20	55,760	533,000	320,000	155,000	23.0	480	510	820	284	173
21	55,860	364,000	332,000	167,000	10.4	492	574	770	295	160
22	56,570	343,000	458,000	87,500	21.9	466	497	860	302	149

* These quantities were measured, but in some cases the values shown

mate of the partial pressure of the oil as a function of vaporization. Latent heats of vaporization were taken into account and in general the original data and the calculations were found to be satisfactorily consistent.

The data do not represent a wide range of vapor inlet conditions as this stream is the major flow of the entire butadiene plant and could not be varied conveniently. This is not considered to be a serious limitation upon the usefulness of the results as the actual vapor traffic covers the range of normal design rates. An appreciable range of liquid rates and temperatures in each stage is covered by the data.

A summary of the data used in this study is shown in Table 2.

Equation. For the purposes of this paper, the over-all effectiveness of each contacting stage has been defined as the ratio of the heat duty to the mean driving force. As discussed here, it was found advantageous to use a vapor phase enthalpy difference rather than a temperature difference as a measure of the driving force. This ratio should be considered the product of an area term and a transfer coefficient based upon unit area and unit enthalpy difference, although only the value for their product can be determined readily. Accordingly, in equation form:

$$U'A = \frac{Q}{\Delta H}$$

where Q is the heat duty in B.t.u./hr., ΔH is an arithmetic mean vapor phase enthalpy difference in B.t.u./lb., A is the surface area of the liquid in sq.ft., and U' is a coefficient representing both heat and mass transfer and is expressed in units of B.t.u./(hr.)(sq.ft.)/B.t.u. (lb. enthalpy difference).

Duty. The quantity taken as the heat duty in stage 1, in which quench oil is partly vaporized, was the inlet vapor stream cooling duty; and in stages 2 and 3, in which vaporized quench oil is condensed, the sensible heat change of the inlet liquid was taken as the duty. The general rule followed was to calculate the stage duty from the change in heat content of the inlet stream which does not undergo a change of state in that stage. Such an expression gives the value for the total or gross rate of heat transfer from the high-temperature stock to the low-temperature stock, and so is analogous to the conventional expression for the duty in an indirect heat exchanger.

Driving Force. The average difference between the actual vapor enthalpy per unit weight of inlet vapor and the enthalpy of the same material at equilibrium with the liquid at the liquid temperature was chosen as a measure of the driving force. This results in a value of zero driving for the force at equilibrium. The average driving force was taken as the arithmetic mean of the values at each boundary of the stage.

It should be noted that enthalpy is not rigorously a measure of driving force. The reason that this function has been used in this case is that it does represent, at least qualitatively, a measure of the separate factors involved in both heat and mass transfer and because the nature and accuracy of the commercial data available would be grossly insufficient to satisfy the complexity of a completely rigorous solution. It is felt that the use of enthalpies in this way has provided a successful correlation of the contacting efficiency of each stage vs. vapor and liquid traffic and a dependable comparison of the relative efficiency of the stages. However, as the calculation method is not ideal, particular care must be taken where the absolute values for stage efficiency are concerned, especially in comparing this system with others of different dimensions or handling other materials.

The usefulness of such an average enthalpy driving force can be illustrated best by considering more closely the conditions in stage 3. Many sets of data show a temperature of the outlet liquid higher than that of the vapor entering, although the over-all result is the heating of the liquid by cooling of the noncondensable vapor and condensation of any remaining vaporized quench oil. A temperature inversion of this sort is commonly found in absorption towers; and the explanation is equally applicable here. The rise in temperature of the liquid is accounted for by the latent heat of condensation of the absorbed fractions. It need only be noted that condensation or absorption can continue as a function of partial pressure and vapor pressure even though the liquid becomes hotter than the vapor. However, it should be noted also that the vapor phase will rise in temperature as long as it is in contact with a warmer liquid. That the heat effect of mass transfer can oppose and even exceed that produced by a temperature gradient is more easily seen in stage 3 than in stage 1, although in stage 1 also, the two effects are in opposition: the hot vapors tend to warm the liquid, while evaporation of the liquid tends to cool it.

An arithmetic mean of the two extreme driving forces in each stage was taken as the average. A logarithmic mean is particularly unsuited to these calculations because in stage 1 the approach to equilibrium is so close that experimental errors are magnified by the use of a logarithmic mean, and because in stage 3 negative driving forces were sometimes encountered.

The individual enthalpies just discussed are most easily calculated by taking liquid temperature at the point in question as the enthalpy reference point. Therefore, the equilibrium en-

SUMMARY OF DATA

Vapor Temps., °F.	Liquid Temperatures, °F.				Vaporized Oil		Calculated Quantities			
Stage 3 Outlet	Stages 2 & 3 Inlet	Stage 1 Inlet	Stage 3 Outlet *	Stage 1 Outlet	Latent Heat B.t.u./lb.	MW	lb./hr. Oil Vaporized in Stage 1	lb./hr. Oil Condensed in Stage 2	lb./hr. Oil Condensed in Stage 3	Temp., °F. Liquid Outlet from Stage 2
90	82	173	124	219	150	155	13,200	8,670	4,530	115
90	82	173	125	219	150	155	13,200	8,630	4,570	115
99	83	171	127	218	150	155	12,500	11,900	600	114
98	83	180	135	226	150	155	15,600	13,600	2,000	126
96	80	188	140	231	150	155	17,600	14,500	3,100	134
94	79	195	145	235	150	155	18,700	15,000	3,700	138
100	80	207	152	245	150	155	22,900	18,900	4,000	142
100	77	220	161	256	150	155	27,600	22,400	5,200	155
95	80	217	150	252	150	155	25,800	12,700	13,100	163
98	80	214	144	252	150	155	24,600	6,300	18,300	174
90	82	196	132	239	150	155	19,200	400	18,800	152
75	77	223	166	258	150	155	28,600	0	28,600	...
138	129	217	178	265	140	164	33,200	23,900	9,300	175
152	100	222	198	297	143	145	45,300	29,000	16,300	167
118	101	217	188	333	143	160	69,600	50,200	19,500	201
118	101	210	183	335	143	162	63,500	45,500	17,000	198
137	118	243	218	288	135	187	86,800	67,500	19,300	218
83	72	206	149	285	145	148	42,200	25,400	16,800	167
90	74	220	173	295	144	158	51,200	40,300	10,900	195
121	115	229	184	278	142	158	47,900	24,200	23,700	181
91	85	202	159	278	152	131	30,900	20,100	10,800	157
120	96	207	185	282	143	154	58,300	37,900	20,400	167

have been adjusted to provide consistent heat and material balances.

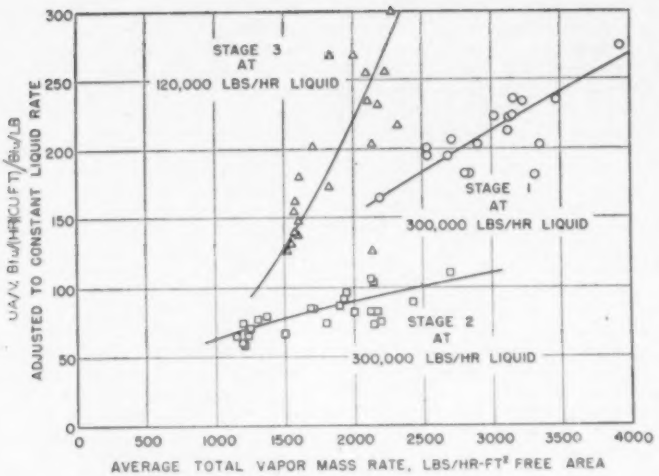

Fig. 2.

thalpy of the vapor phase at this temperature consists only of the latent heat times the weight of vaporized oil, as calculated from equilibrium vaporization curves, per unit weight of noncondensable inlet vapor. The actual vapor phase enthalpy above the same base equals the sensible heat of unit weight noncondensable fraction plus the latent and sensible heat of the quench oil constituents actually in the vapor phase per unit weight of inlet noncondensables. The difference between the two values was used as a measure of the driving force and, as already stated, an arithmetic mean of the two terminal driving forces was taken.

As an example, consider the computation of a typical driving force at the vapor inlet to stage 2, based upon the first set of data in the tabular summary. The vapor stream at 268° F. contains, for every pound of noncondensables, 0.297 lb. of quench oil which has been vaporized in stage 1. The outlet liquid temperature upon which the enthalpies at this point are based is 118° F. and the respective heat capacities are such that the sensible heat content of the noncondensables is 74 B.t.u./lb. and that of the condensables, 66 B.t.u./lb., above 118° F. At the same liquid temperature, the equilibrium between the streams at this point would leave 0.0264 lb. of oil still vaporized/lb. of noncondensables. Finally, the latent heat of this vaporized fraction is 150 B.t.u./lb. The actual vapor enthalpy is equal then to $74 + 0.297 \times (66 + 150) = 138$ and the equilibrium vapor enthalpy $= 0.0264 \times 150 = 4$. The difference or driving force said to exist at this point is therefore $138 - 4 = 134$ B.t.u./lb.

A similar enthalpy per unit weight of the total vapor might be used to compute a driving force, but results based upon such a value were found to be less precise than those obtained by basing enthalpies upon the unit weight of noncondensable vapor.

Results. To facilitate the comparison of the three stages, the over-all stage performance calculated as just discussed has been divided by the active volume in cubic feet, of the stage. In stage 3, for example, there are seven trays occupying a volume of 1100 cu.ft. to be compared with only four trays in stage 2, taking up 786 cu.ft., while the volume of the spray in stage 1 is 481 cu.ft. Results so expressed for each stage are believed to be on a more nearly comparable basis, although the effects of dimensions are not completely eliminated by this means.

The expression $U'A/V$ over-all units, B.t.u./(hr.)(cu.ft.)/B.t.u./lb. was found to vary with both liquid and vapor rates. For correlation purposes the vapor rate was taken as the arithmetic average of the total inlet and outlet vapor mass rate expressed in pounds per hour per square root of free area. Liquid rate was expressed as the arithmetic average of the total inlet and outlet streams, in units of pounds per hour, as there was no definite cross-sectional area involved in the flow of the unconfined liquid.

Vapor Rate Correlation. The effect of vapor rate upon $U'A/V$ is shown in Figure 2. For this chart the original values of $U'A/V$ were adjusted to a constant liquid rate for each section by means of the correlation shown here. In general it is reasonable that the heat-transfer effectiveness should rise with increasing vapor velocity inasmuch as the vapor-film resistance ordinarily is an appreciable part of the total resistance to heat and mass transfer. Furthermore, the variables other than vapor velocity in the common vapor film coefficient expressions, heat capacity, viscosity, and Prandtl number, are comparatively constant in any one stage so that in the absence of any effect of the vapor rate upon the liquid surface area, the $U'A/V$ values might be expected to vary as the eight-tenths power of the vapor mass rate if the vapor film resistance controls. Such a relation is closely followed by the points for stage 1; those for stage 2 more nearly follow a five-tenths power, while those for stage 3 seem to vary with the square of the vapor mass rate. It is indicated, therefore, both that vapor rate does affect liquid surface area and that a liquid film forms an appreciable part of the total resistance, with the first effect predominating in stage 3 and the second in stage 2. If these two effects are present in stage 1, it is evidently to such an extent that they cancel each other.

Liquid Rate Correlation. Figure 3 shows the relation between the $U'A/V$ values and the liquid rates. The original $U'A/V$ values were adjusted for this chart to a constant vapor velocity by using Figure 2. Similarly, these are the curves which were used to provide the adjustment to a constant liquid rate for Figure 2.

Considering the effect of liquid rate it appears reasonable to predict that $U'A/V$ will increase with liquid flow at low values of flow rate largely as a result of the creation of more surface area. It is unlikely that liquid rate affects the over-all coefficient of heat and mass transfer appreciably because, being unconfined in any of the stages, the liquid surface velocity does not depend upon liquid flow rate. It might be anticipated further that less and less incremental area would be produced at higher values of liquid flow, depending on the specific installation, and that the area might actually go through a maximum with respect to liquid rate.

Curves for stages 1 and 2 show a continuous rise of $U'A/V$ with increasing liquid rate although the effect is less for stage 1, the spray tower, than for stage 2, disc-and-doughnut baffles. As just discussed, it is believed that the effect is a result of an increase in the area term of $U'A/V$.

However, in stage 3 a decrease of $U'A/V$, and therefore supposedly in area, occurs with increasing liquid rate. A possible explanation for this decrease in liquid surface area with an increase in liquid flow is that more and more of the perforations in the rain decks are fed with a head of liquid sufficient to form an unbroken stream rather than a shower of droplets. Two facts support this theory. One is that the calculated average head of liquid over the perforations at even the highest liquid rate shown to stage 3 is so small (only a small fraction of an inch) that a solid stream of liquid through all the holes is quite improbable. The second fact is that a liquid depth of more than an inch over the entire tray is necessary to account for the holdup indicated by the loss of level in the bottom of the column when liquid flow is increased to high rates. It seems likely that an appreciable depth of liquid does not exist over the entire tray but over only the unperforated surface and a few adjacent rows of holes. As a result, the holes so covered handle the greater part of the liquid traffic; but the solid stream that flows through them has much less surface area than the droplets which fall from the holes not completely submerged. According to this explanation, it is reasonable that the maximum area would occur at a rather low liquid rate, specifically, that rate that could be handled by the tray entirely as droplets. Moreover, the relatively steeper slope of the vapor mass rate correlation for this stage can be accounted for by noting that high vapor rates would be able to break into droplets more and heavier streams of liquid than would low rates.

Using Figures 2 and 3 it is possible to obtain approximately relative values of $U'A/V$ that would apply if all three stages were operated at the same vapor and liquid rates. In this manner the effects of operating conditions on performance are isolated and removed, allowing a comparative evaluation of the different types of contacting equipment on a unit volume basis. It is then evident that stage 1, the conflow spray tower is superior to stage 2, disc-and-doughnut baffles over the entire range of vapor and liquid rates studied. Stage 3, the perforated rain deck section, is more effective than either of the other sections at low liquid rates and high vapor rates, but would be about equal to stage 2, at high vapor rates and low liquid rates.

Significance and Use of Results

Results of this study indicate the relative effectiveness of three types of direct-contact vapor quenching equipment. The range includes operating conditions that would probably be selected in designing this type of equipment. No similar performance data for direct contact quenching with which the results of this investigation might be compared are known, but the self-consistency of the calculated results and the logical manner in which they vary with operating conditions indicate reliability.

In the design of a direct contact vapor-quenching system the data contained herein, together with cost and pressure-drop considerations, would indicate the most desirable type of equipment. The approximate volumetric size of the equipment selected would then be established for the design conditions from the correlations depicted on Figures 2 and 3, and the usual column capacity and pressure-drop relationships would be used to determine the most suitable dimensions corresponding to the indicated volume.

Well worth emphasizing are the advantages offered by a two-stage direct contact vapor quenching system, in which the first stage is conflow and the second countercurrent. In such a process the temperature difference available for heat exchange is greatest at the point where most rapid cooling is desired and such cooling is favored considerably by evaporation of the liquid coolant. The effect is equivalent to increasing the heat capacity of the liquid, thereby extending the duty that can be obtained from a given liquid temperature rise. If, as often happens, there is a critical temperature below which the gaseous phase must be rapidly cooled to prevent undesirable chemical or physical changes, it can be effectively accomplished in such a process. The remaining heat duty, which may now consist largely of condensing the vaporized coolant, can be performed with small, even negative, temperature differences in a countercurrent column, essentially an absorbing section.

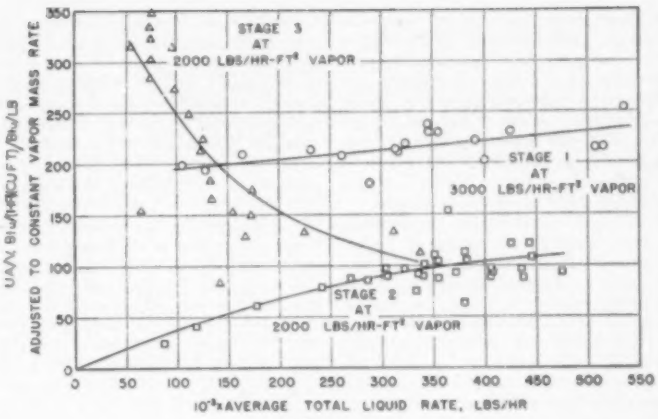

Fig. 3.

The conflow direct contact exchanger imposes no limit on the amount of turbulence which may be produced in order to approach equilibrium more rapidly. In this case apparently adequate mixing occurs in an empty tower, presumably as a result of the high vapor velocity in the inlet line. More generally, however, there seems to be no reason why this section need be designed otherwise than as a vapor-liquid mixer, relying on the following countercurrent stage to remove entrained liquid.

It seems that even the system described herein could be further simplified in future designs. Only one countercurrent stage of adequate size may be necessary; this would make the original installation less expensive and would reduce the uncertainties in designing this part of the system, as presumably the outlet conditions would be known. It might also be desirable to increase the driving force in the first stage by taking quench oil for this stage from the cold circulating stream out of the coolers instead of from the hot stream to the coolers, but this would depend upon the economics of each particular case.

Acknowledgment

The authors are indebted to the California Research Corp. for providing the opportunity for making this study and to the Reconstruction Finance Corp., Office of Rubber Reserve, Standard Oil Company of California, and California Research Corp. for permission to publish the results.

Discussion

G. T. Atkins (Humble Oil & Refining Co., Baytown, Tex.): We have a rather similar butadiene process at Baytown, which was also developed during the war. Although the equipment differs in some respects, yet, in the quench process, where the vapors are cooled, we, also, distinguish three stages or zones of cooling. The first zone consists of an oil spray concentric with the pipe, in concurrent flow. The second zone consists of three trays of bubble caps, and the third zone consists of indirect heat transfer, or final cooling. We find that the first zone is necessary when bubble caps are used. Otherwise, coke and deposits can be expected in the risers and caps of the lowest bubble deck, due to the drying-out effect of the hot gases on the quench oil liquid and the polymers dissolved in it. We, also, had temperature differences to deal with in considering the efficiency of the bubble-cap plates. Was the "temperature efficiency" concept by any chance used in connection with either the disc and doughnut or the perforated plate sections of the second and third zones? In the literature, there is a plate efficiency concept, which uses temperature differences as driving forces for the expression of tray efficiency. It is contained in the first edition of Perry's "Chemical Engineers' Handbook." (*2*) It is a theory that was current at one time, which deals with the efficiency of bubble trays for heat-transfer processes.

R. J. O'Donnell: We did not look into that. Thank you for the information.

Written Discussion

B. H. Golding and B. H. Sage (California Institute of Technology, Pasadena, Calif.): The authors have presented information derived from the operation of equipment used in the cooling of gases by direct contact with petroleum oil. The process was divided into three stages, the first of which was a concurrent spray cooler in which a

substantial part of the oil was evaporated. The second stage involved a series of spray decks where the preponderance of the energy exchange was associated with conduction and partial condensation of the evaporated oil, and the third was apparently operated primarily as an absorber to remove from the gas phase the evaporated oil and possibly other heavy hydrocarbons.

A rough correlation of the hydrodynamic conditions is made and performance is treated on a basis of unit volume, as is customary when it is difficult to evaluate the area of the cooling surface. The qualitative behavior found is not unexpected and the quantitative results within each stage appear of design value. Although the authors compare the over-all effectiveness of the three stages, it is believed that additional information must be accumulated on similar pieces of equipment before efficacy of the procedure can be established. It appears that there exists a particularly marked difference in the hydrodynamic conditions obtained in stage 1 as compared with those in stages 2 and 3. A somewhat more basic correlation might be available if detailed consideration were given to the hydrodynamic conditions obtaining in each of the three stages.

The authors have employed a combined coefficient based upon enthalpy as a potential and related to the transfer of both thermal energy and material. The over-all effectiveness of such a combined coefficient appears to be limited. From the measurements indicated, it seems that enough material was at hand to make a reasonable approximation of the actual material and thermal transfer in each stage. If such is the case it is believed preferable to present the results on the basis of a thermal transfer coefficient and of a material transfer coefficient each involving a separate potential. The authors have apparently employed enthalpy as the potential on the basis of earlier use of this thermodynamic function in such a capacity (*1*). In the opinion of the authors of this discussion enthalpy does not possess all of the basic characteristics of a potential for either thermal or material transfer processes nor is the enthalpy of a liquid and gas phase at equilibrium equal. It is believed that the chemical potential or a related quantity fugacity might be a useful potential for material transfer, while temperature is the commonly accepted potential for thermal transfer. Coordination of the data indicated by the authors on the basis of enthalpy as the potential is perhaps in itself sufficient justification for such a method of calculations. However, it is not believed that the use of enthalpy as a potential and of an over-all coefficient is the most desirable appro ch to a situation of this character.

It is believed that further information concerning thermal transfer under conditions of direct contact between the phases will yield design information of immediate value. Continued experimentation upon such problems under carefully controlled conditions will yield additional basic data regarding the nature of such transfer processes and should ultimately permit the prediction of such behavior with an uncertainty comparable to that with which the configuration of the interfacial areas of contact may be described.

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(*Presented at Los Angeles (Calif.) Meeting.*)

LETTERS TO THE EDITOR

PRESSURE DROP THROUGH POROUS MEDIA

Sir:

The paper by Brownell et al (*1*) proposes a revision of the pressure drop correlation presented in Part 1 (*2*) of this series. The novel attempt was then to consolidate packed bed pressure-drop data along the methods of Moody and Nikuradse who considered the effect of surface roughness in open circuits. With some modifications the packed-bed data were expressed in this way, which had to result in rather arbitrary and comparatively inconsistent assignments of surface roughness values to the various materials described in the literature, since absolute measurements were not and still seem not available to date. In the present revision the effect of surface roughness has been dismissed on the basis of evidence which is open to question.

It is not intended to discuss the general eccentricity of the correlations, but rather to point out and correct a confusing presentation of the relative effects of surface roughness and bed voidage on the pressure drop, as well as to analyze the evidence on the basis of which surface roughness effects have been dismissed.

Admittedly, the relative effect of surface roughness upon packed bed pressure drop in turbulent flow is of a smaller order of magnitude than would be expected in open circuits, because in the former fluid expansions, contractions and local velocity-head variations are primarily responsible for the resistance. Since these factors are chiefly dependent on bed voidage, it is apparent that the voidage effect on pressure drop must be established first. With this accomplished, it is then quite permissible to propose a packed bed friction factor correlation along the methods of Nikuradse, *provided* the resulting friction factors *fall by themselves* into definite groups as characterized by materials. Although orientation effects may be important, it has been shown (*3*) that pressure drops in dumped beds may be duplicated satisfactorily for the same material if the beds in question have identical voidage.

Following this line of reasoning, data have been collected (*5*) in an effort to demonstrate the roughness effect. As a matter of convenience and simplicity the friction factor presentation was found satisfactory. The correlation has been applied to packings of various surface conditions with good results, as is apparent from Figure 1. Materials *a*, *b*, *d* and *e* were of clay and fused magnesia and are generally considered rough, whereas *c* pertains to brass rings with little or no surface roughness. Correlations for smooth (*4*) and rough (*5*) particles are identical, except for the magnitude of the friction factor.

The authors must have been unaware of this development, or they could not possibly have compared their Raschig ring data with the correlation which is valid only for smooth particles, such as glass, metals and certain types of extruded catalysts. Naturally the predicted data were low and the impression has been advanced that the correlation is at fault as far as voidage is concerned. This, of course, is not true as Figure 1 shows quite clearly. The limits of the correlation as far as voidage is concerned are near 75 to 80 per cent. The authors have used this correlation further in an attempt to predict values for their smooth nickel saddles, for which a porosity of 93.1% was reported.

Extension of the equation into this range violates, however, one of the basic assumptions underlying its derivation, namely, that the size of the voids in a packed bed must be of the order of magnitude of the particles in order for the correlation to apply. At voidages above 90 per cent this is of course not true, and for this reason no agreement *should* be expected. In an attempt to show by comparison the relative merits of the revised correlation, the authors have similarly overextended themselves in the use of the correlations of Carman, Chilton and Colburn and Rose.

Examination of Figures 1 and 2 indicates that the present revised form merely indicates the order of magnitude for most of the data. It will suffice to state that the deviations are primarily due to the fact that the revised form is in itself inconsistent as far as voidage effect on flow resistance is concerned. Returning now to roughness, its effect was dismissed on the basis of smooth and so-called "roughened" nickel saddles, having a bed voidage of about 93%. Contrary to expectations, the rough saddles were found to give pressure drops which were approximately 40% below the smooth saddle data. This significant difference was lightly dismissed on the basis that the smooth bed voidage was 93.1% compared to 93.5% in the rough saddle bed, an explanation hardly acceptable. It is unfortunate that it was decided to use the fringes of the revised correlation to recognize so disputable an effect as surface roughness is believed to have. Not only does it appear that the correlation may be considerably in error in this voidage range, but from a purely experimental point of view, the relative errors are much more serious in this voidage region than, say, at 40 or 50%. Considering for the moment the possibility that the smooth and rough saddle deviation was due to the experimental error, a deviation of 40% in pressure drop could have resulted by an uncertainty of only 2-3% in the voidage measurements. In view of these facts, definite conclusions do not seem justified at this time.

Max Leva

Pittsburgh, Pa.

The authors appreciate this opportunity to discuss flow through porous media with Max Leva who takes issue with us regarding the effect of roughness in porous media.

Data presented in Part IV (*1*) were taken with two objectives in mind. One —to investigate the high porosity region, and two—to investigate the effect of roughness. Rough conduits are known to give different friction factor-Reynolds number curves than smooth conduits.

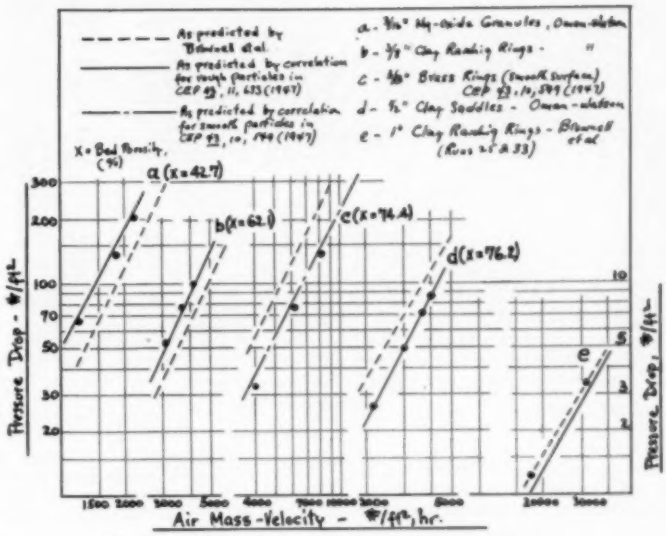
As predicted by Brownell et al.
As predicted by correlation for rough particles in CEP 43, 11, 633 (1947)
As predicted by correlation for smooth particles in CEP 43, 10, 599 (1947)
a - 3/16" Mg-oxide Granules, Oman-Watson
b - 1/2" Clay Raschig Rings - "
c - 1/2" Brass Rings (Smooth Surface) CEP 43, 10, 599 (1947)
d - 1/2" Clay Saddles - Oman-Watson
e - 1" Clay Raschig Rings - Brownell et al (Ross 2nd A 33)
X = Bed Porosity, (%)
a (x=42.7)
b(x=62.1)
c(x=74.4)
d(x=76.2)
e
Pressure Drop - #/ft²
Pressure Drop, #/ft²
Air Mass-Velocity - #/ft², hr.

Fig. 1. Comparison of correlations with literature data.

Both rough and smooth conduits have the same friction factor curve in the laminar region but the break from the 45° laminar line and the slope of the curve thereafter vary with the surface roughness. We anticipated that this difference in slope in the turbulent region would also be apparent in the friction factor-Reynolds number curve for porous media. However, because of the other variables, porosity, shape, packing arrangement, etc., a single curve in which this effect might be observed for particles of known roughness can only be obtained if the complete range from laminar through transition to

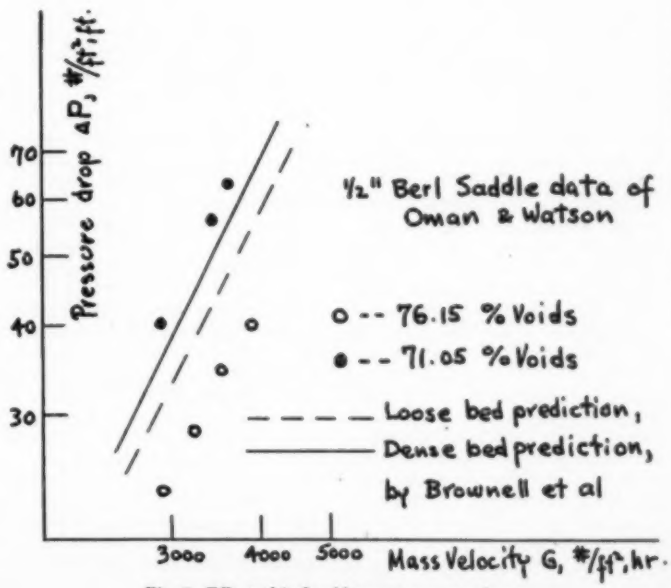
Pressure drop ΔP, #/ft²/ft.
½" Berl Saddle data of Oman & Watson
o -- 76.15 % Voids
● -- 71.05 % Voids
Loose bed prediction,
Dense bed prediction,
by Brownell et al
Mass Velocity G, #/ft², hr.

Fig. 2. Effect of bed voidage on pressure drop.

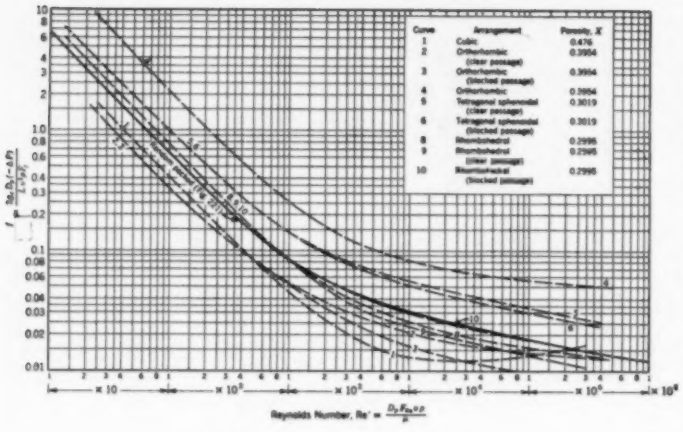
Curve | Arrangement | Porosity, ε
1 | Cubic | 0.476
2 | Orthorhombic (clear passage) | 0.3954
3 | Orthorhombic (blocked passage) | 0.3954
4 | Orthorhombic | 0.3954
5 | Tetragonal sphenoidal (clear passage) | 0.3019
6 | Tetragonal sphenoidal (blocked passage) | 0.3019
8 | Rhombohedral | 0.2595
9 | Rhombohedral (clear passage) | 0.2595
10 | Rhombohedral (blocked passage) | 0.2595
Reynolds Number, Re' = D_p F_m ρ / μ

Fig. 225 ("Unit Operations"—Brown).

highly turbulent flow is measured with the other variables held constant. When only a portion of the turbulent data is available as was the case with Leva's data (*5*) slopes are difficult to evaluate.

Therefore in the experimental work of Part IV great care was taken to check the porosity of the bed before and after runs to assure that there was no change. Several runs had to be discarded when compaction was discovered. Figures 8 and 9 of Part IV show sets of data for both large and small particles of various degrees of roughness and ranging in porosity from 40 to 94%. The remarkable observation is that the curves all have identical shapes, indicating no such roughness relationship as occurs in conduits. We admit we did not anticipate this result but in view of the carefully measured data we had to revise our concept of the effect of roughness. We have reached the conclusion that roughness has no appreciable effect on the shape of the Reynolds number friction factor curve and therefore all curves for random packed porous media may be correlated to one line. We still believe that roughness must have some effect, but that the effect will have to be evaluated in stacked beds where the deviations due to orientation in random packing may be eliminated. The effects of orientation are not as small as Leva infers. Figure 225 from "Unit Operations" by Brown and associates shows the work of Martin on beds of stacked spheres. Curves 2 and 4 have identical porosities but differ by about 600% in friction factor as a result of different packing arrangements. It is true that this effect is much smaller in random packed beds. However, as the roughness effect likewise is small in magnitude, we believe the effect of packing arrangement must be eliminated before the effect of roughness can be firmly established.

Another point regarding roughness is that the extremely rough nickel saddles used by the authors gave a friction factor curve lower than the curve for smooth nickel saddles. Leva attempts to explain this difference by suggesting an error in our porosity measurements. We do not appreciate this brief dismissal in view of the care exercised in taking the data. Both porosities were measured in the same apparatus by the same method so that if an error had been made it would be of an absolute nature appearing in both porosity values and therefore would still refute Leva's comments. We were forced to conclude that roughness has such a small effect on flow through porous media that it should not be included in our revised correlation.

Now to consider briefly the figure submitted in Leva's discussion. This figure shows that Leva's correlation agrees with the data on which it is based as is indicated by curves "*a, b, c, d.*" Leva reports an average deviation of ±8% (*4*). The authors agree that Leva's correlation for rough particles (*5*) gives good agreement with the authors' data on pressure drop for the Raschig rings as is shown by curve *e*. Similarly the author's correlation (1) agrees with the data on which it is based as shown by curve "*e*". The authors found an average deviation of ±6% and a maximum deviation of ±24% (*1*). In curve "*a*" the important variable, sphericity must be estimated, therefore this curve cannot be used to prove any argument. The authors' calculations show that the authors' correlation (*1*) checks the data in curves *b, d,* and *e* within 11%, 2% and 0% respectively, which is within the reported deviations.

For the benefit of the readers we wish to point out that all correlations for flow through porous media are empirical relationships based on the most reliable data available to the respective authors. Each correlation has its own particular merits and limitations. Some of these limitations will be described. The Kozeny or Carman equation is limited to laminar flow. The Chilton-Colburn relationship makes no allowance for the important variables, porosity and sphericity. The integration required in using the method of Rose complicates the calculations without any increase in accuracy. As Leva points out in his discussion, his correlations (*4*) are limited to a maximum porosity of 75 to 80%. The Brownell-Katz relation described in Part I (*2*) becomes inconvenient when used with beds of high porosity because of the high exponent on the porosity term.

The revised correlation of authors (*1*) may be used to predict laminar, transition, and turbulent flow through porous media over a porosity range from 40% to 94%. However, this is a limitation, because the ideal relationship should cover the complete porosity range from 0 to 100%. The authors at present are studying the range from 40% downward and anticipate expanding the range of their correlation as additional new data are obtained.

L. E. Brownell

Ann Arbor, Mich.

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EFFECT OF VAPOR AGITATION ON BOILING COEFFICIENTS†

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Boiling coefficients were measured between the outside of four horizontal copper tubes in a vertical row and boiling Freon 12. The effect of one tube on the heat transfer for another is reported for heat fluxes from 874 to 35,100 B.t.u./(hr.)(sq.ft.). Vapor was injected below a single tube for a series of injection rates and boiling temperature differences. Boiling coefficients for Freon 12 on copper tubes ranged from 260 B.t.u./(hr.)(sq.ft.)(°F.) at a temperature difference of 7° F. to 1600 at a temperature difference of 19.5° F.

THE purpose of this investigation was to study boiling coefficients for Freon 12 on the outside of horizontal tubes under conditions resembling those in a commercial tube-and-shell water cooler. The effect on the boiling coefficient of agitation resulting when bubbles from one tube strike the tube above or when vapor is artificially introduced beneath the tube bundle was studied for four tubes in a vertical row for a series of heat loads at different evaporating temperatures. Nuclear boiling occurs for the low-temperature differences employed.

It has been general practice to correlate boiling coefficients in the nuclear region on the basis of the difference in temperature between the heating surface and the liquid. Practically all previous studies (*4-9*) indicate that for boiling from plain surfaces in the vertical or horizontal position, the rate of heat transfer decreases rapidly as the temperature difference is decreased. The coefficients for given liquids have been represented by an equation of the type

$$h = E(\Delta T_b)^m \qquad (1)$$

where h is the boiling coefficient based on the area on which boiling is taking place in B.t.u./(hr.)(sq.ft.)(°F.); E is a constant which depends largely on the liquid and the surface; ΔT_b is the temperature difference between the boiling liquid and the interface across which heat is being transferred in °F.; and m is a constant which apparently lies between 2.4 and 2.6 for most liquids (*4, 7*). This indicates the rapid rise in the heat-transfer coefficient with temperature difference, and hence its relatively low value at low-temperature differences.

Contrary to the above equation, data presented by Austin (*3*) for boiling under violent mechanical agitation indicate no change in heat-transfer coefficient with temperature difference for boiling water. These data indicate that temperature difference is not the only major fundamental variable, even for a given liquid boiling on a given surface. The dynamics of the boiling liquid also seems to have a dominant effect. Therefore, it is reasonable to assume that the tube arrangement and vapor-liquid flow pattern around the tubes will significantly affect the rate of heat transfer in a horizontal tube-and-shell evaporator. The effect of agitation induced by external means should be particularly apparent at low boiling rates, where normal agitation is relatively poor.

Previous work in this field has been limited; most investigations have been confined to a study of boiling coefficients for single tubes or of average values for a number of tubes in a bundle. Ashley (*2*) studied heat-transfer coefficients for Freon 12 in a direct-expansion-type double-pipe exchanger. Jones (*10*) reported average coefficients for evaporating Freon 11 in a 430-ton cooler having integral spiral low finned tubes. Akin (*1*) attempted to study the boiling

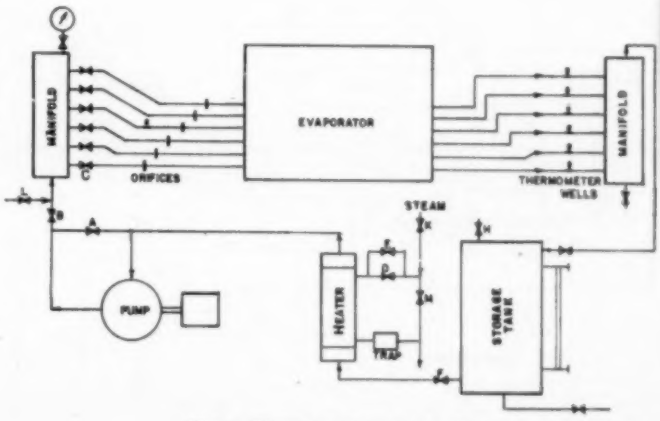

Fig. 1. Flowsheet of water circuit.

† This paper in its entirety is obtainable on loan from the University of Michigan Library.

‡ Present address: University of Alberta, Edmonton (Alta.), Canada.

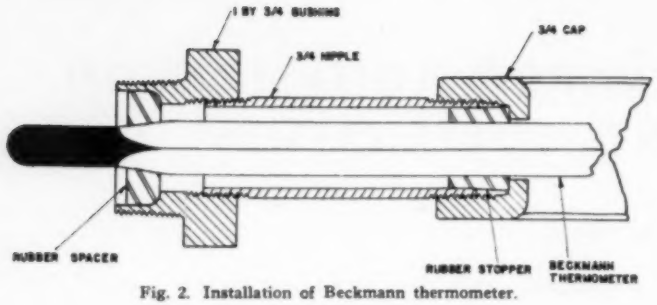

Fig. 2. Installation of Beckmann thermometer.

coefficient for water for separate groups of 12 tubes in a short 60-tube evaporator. Jakob (*9*) in his studies on boiling water from vertical surfaces, has referred to the stirring effect of the rising steam bubbles.

Experimental Method

The method adopted in the present investigation was to study rates of heat transfer to individual horizontal tubes placed in a vertical row in an evaporator. The boiling liquid was Freon 12, and the heat load was provided by water recirculated through the tubes. Water inlet and outlet temperatures and flow rates were measured for each tube to get the heat load. The tube wall and Freon temperatures were measured to determine the boiling temperature difference.

Studies on the effect of artificially introduced Freon vapor were made by passing known quantities of vapor at a given temperature and pressure through a perforated tube located beneath the bottom tube in the bundle.

Water System

The flow sheet for the water circuit is shown in Figure 1. The water, heated by the steam heater to maintain constant inlet temperature to the evaporator, was pumped through the individual tubes in amounts controlled by by-pass valve *A* and inlet valves *C*. The storage tank permitted sufficient holdup in the system to facilitate temperature control.

The individual water pipes leading to the evaporator tubes were standard ½-in. pipe. Orifices placed in each pipe as indicated permitted reading flow rates in the evaporator tubes up to 12 ft./sec. Manometer leads from each orifice led to a suitable manifold and mercury manometer. The orifices (Diameter 0.334 in.) in tubes 1 (bottom tube), 2, 3, and 4 were 27-, 24-, 21-, and 18-pipe diameters upstream from the evaporator. Each orifice was calibrated in place with water.

Inlet and outlet water temperatures were measured with Beckmann thermometers located in one-inch pipe tees as indicated in Figure 1. One thermometer, was installed in the fourth tube from the bottom 24 in. upstream from the evaporator to measure the inlet temperature. A thermometer was installed in each of the bottom four tubes 30 in. downstream from the evaporator to measure outlet temperatures. In the bottom tube, which ran straight from the evaporator to the manifold, a mixing chamber was located ahead of the thermometer well.

The method of installing the Beckmann thermometers (Fig. 2) proved successful in that it permitted removal of the thermometer from the well without breaking a rubber to glass seal whenever the setting on the thermometer had to be changed.

Freon System. The flowsheet for the Freon circuit is shown in Figure 3. High pressure Freon gas was supplied to the condenser from a compressor operating 3 cylinders at 1750 rev./min. from a 5-hp. drive. High pressure liquid from the condenser was delivered to the vapor-liquid separator where it was throttled by hand expansion valve *C* to approximately the evaporator pressure, the flashed gas going back to the compressor suction, and the liquid flowing by gravity into the evaporator. The liquid level in the separator was indicated by a sight glass.

The capacity of the compressor was controlled by by-pass valve *F* and the compressor temperature was controlled by flashing high-pressure liquid through valve *H* from the condenser to the suction side. Vapor from the evaporator was returned directly to the suction side of the compressor.

Evaporator. The evaporator (Fig. 4) was constructed to provide a bath of Freon around the tubes. A removable tube bundle (Fig. 5) contained tubes other than those through which heat was transferred. Figure 6 shows the tube arrangement and section of the tube sheet. One end of the bundle was gasketed to a cover plate while the other end was packed to permit removal or movement of the sheet.

An assembly drawing of the evaporator appears in Figure 4. The evaporator measured 17¼ in. high by 7¼ in. wide by 38½-in. long inside and was fabricated of ½-in. steel plate welded at the seams and reinforced at three positions with 3-in. steel *I*-beams welded in place. Glass windows welded into the sides permitted visual observation of the boiling and the liquid level. The unit was pressure-tested at 225 lb./sq.in.

The tube bundle consisted of 16 0.750 O.D. plain tubes having a 0.065-in. wall thickness rolled into the tube sheet. The distance between tube sheets was 36.2 in. giving an area of 0.593 sq.ft./tube. Water connections were completed to the six tubes in the middle row of the tube bundle but only the bottom four tubes were equipped with thermocouples. Each tube had three thermal junctions, one of which was in the middle and the other two 4 in. from each end. The junctions in tube 1 (bottom tube) were placed one on the bottom, one on the side, and one on the top. The junctions in tubes 2, 3, and 4 were all on the bottom. The junctions consisted of No. 30 copper and constantan wires in indirect contact ¼ in. apart at the center of the tube wall. The wires were led from the tube out of the equipment inside 0.032 in.-O.D., 0.020-in. I.D. stainless steel tubing. The end of each stainless tube was embedded for 15/64 in., in the copper wall, but only the tip of the wire made electrical contact.

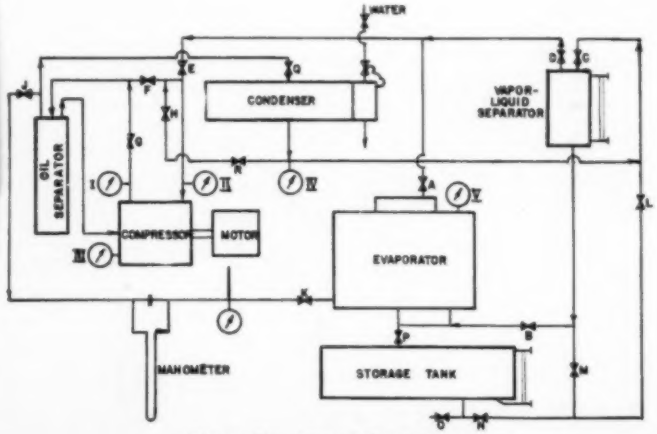

Fig. 3. Flowsheet of Freon circuit.

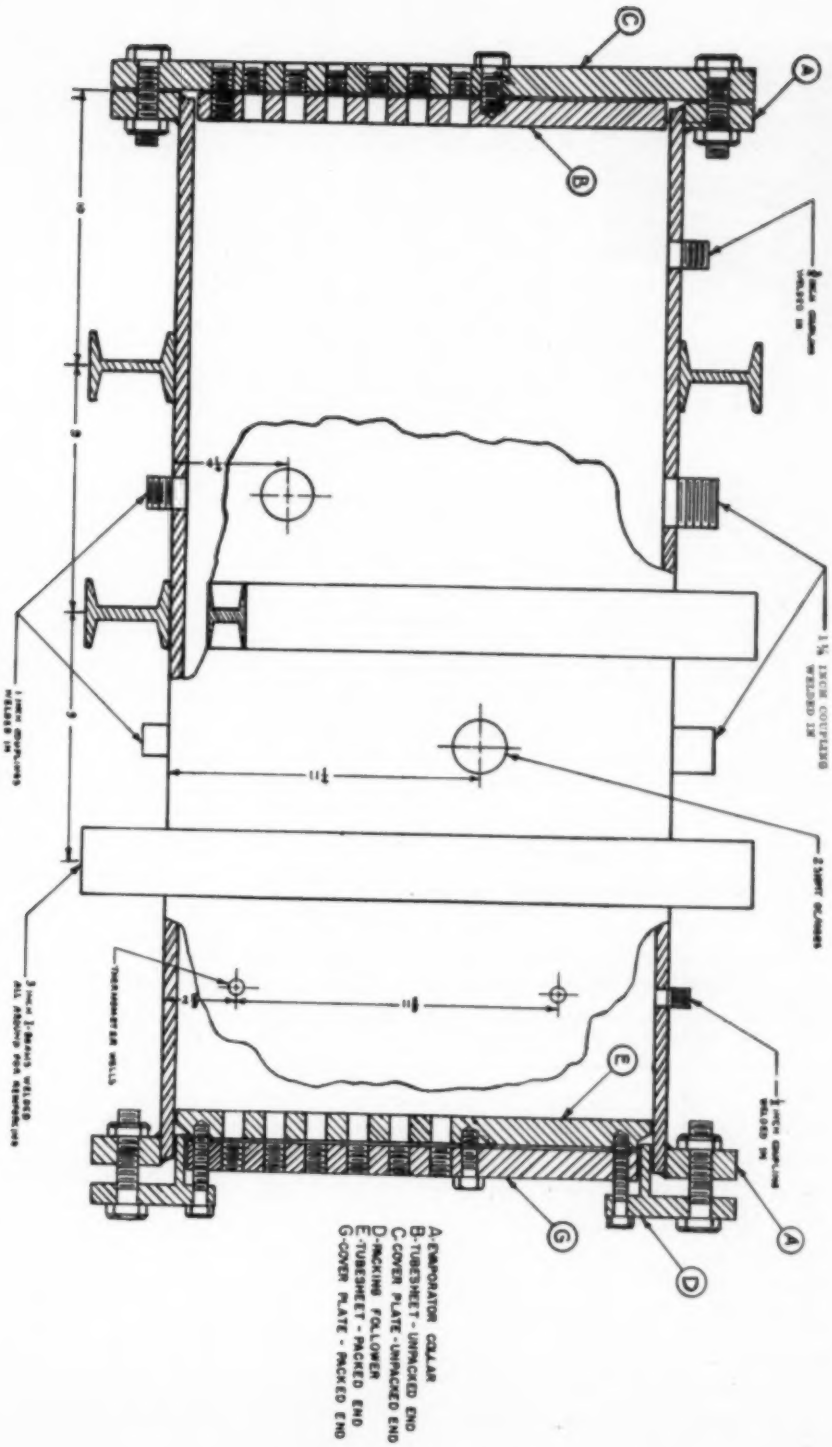

Fig. 4. Evaporator assembly.

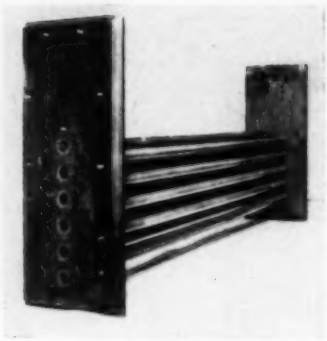

Fig. 5. Tube bundle.

TABLE 1

Example Data for Vapor Injection on Bottom Tube

Run No.	Water Temp. In °F	Water Temp Drop °F	Heat Flux BTU/hr sq. ft.	Avg. Tube Wall Temp. °F	Freon Temp. °F	ΔT_b °F	h BTU/hr. sq.ft.°F	ΔT_1 °F	h_1 BTU/hr sq.ft.°F	Vapor Rate cu.ft./hr
154	78.48	3.649	32400	58.30	39.65	18.25	1776	17.95	1805	
155	78.48	3.647	32400	58.40	39.65	18.35	1769	17.86	1814	46.9
156	78.48	3.665	32550	58.40	39.65	18.35	14	17.85	1823	78.5
157	78.48	3.689	32700	58.35	39.65	18.30	90	17.88	1829	110.0
158	70.19	2.871	13470	55.70	40.90	14.63	919	12.88	1045	
159	70.19	2.912	13650	55.46	40.80	14.43	945	13.16	1037	46.1
160	70.19	2.957	13860	55.06	40.85	14.04	985	13.48	1027	77.6
161	70.25	2.986	14030	54.90	40.90	13.83	1030	13.59	1032	113.2
162	70.90	2.365	7080	60.00	48.70	11.21	629	9.63	736	
163	70.90	2.419	7240	59.55	48.70	10.76	671	10.05	721	47.1
164	70.90	2.463	7480	59.16	48.75	10.34	720	10.40	718	78.4
165	70.88	2.558	7550	58.82	48.65	10.07	760	10.68	707	110.0

The Freon temperature was measured with two thermocouples, one placed opposite tube 2 and one opposite tube 4.

The perforated vapor injector was made from a piece of ½-in. pipe threaded into the tube sheet at the unpacked end so that it was ½ in. from the bottom tube. Twenty-three holes 0.040 in. in diameter were drilled 1½ in. apart in a straight line along the top of the pipe. The vapor was directed through these holes against the bottom tube. The outlet end of the pipe was capped. Injected Freon gas was admitted by opening valves *J* and *K* (Fig. 3). The rate was measured by an orifice calibrated in position with air.

The evaporator was thoroughly insulated with rock cork and hair-felt insulation and waterproofed with black tape covered with two layers of asphalt paint. All the other low-pressure auxiliary Freon piping and equipment and the complete water system were insulated with hair felt and waterproofed.

Collection of Data

The water circulation system and the Freon system were started up in order. As soon as conditions had been steady for about 15 minutes and usually about 1½ hours after starting up, data were taken. The lower Freon liquid thermocouple was read, followed by the tube wall temperatures for tube 1. While the middle couple was being read, the inlet and outlet water temperatures were also read. This procedure was repeated for the other three tubes, with the upper Freon liquid couple being read for tubes 3 and 4. Three complete cycles of readings were made at each condition. The water manometer was read at the beginning and end of each run.

As wide a range of inlet water temperatures, evaporating temperatures, and water velocities as possible was covered for each particular setting on the Beckmann thermometers. In some cases, where the heat load or water velocity was especially high, only two tubes could be operated. At exceptionally low heat loads, top tubes 5 and 6 were run to facilitate control of the compressor.

Runs taken with Freon gas being introduced beneath the tubes were essentially the same as the others except that the desired quantity of gas was introduced through the injector. No difficulty was encountered in keeping the flow rates constant. The temperature and pressure of the inlet gas were recorded when the manometer was read. One series of data was taken with all four tubes in operation while gas was being injected and another series was taken for the bottom tube only. Data in Table 1 are typical for the series taken on the bottom tube only.

TABLE 2

Measured Temperatures for Tube Wall

Tube	Inlet Water °F	Measured Average Temperatures: First Couple °F	Middle Couple °F	Last Couple °F	Outlet Water °F	Heat Load BTU/hr
1	62.05	49.83	48.90	49.40	59.71	11880
1	65.15	53.96	53.60	54.65	62.48	2440
2	62.05	49.20	49.93	50.70	59.62	12120
2	65.15	52.70	52.65	53.37	62.31	2590
3	62.00	49.09	49.06	49.86	59.64	11830
3	65.15	52.48	52.48	52.55	62.23	2670
4	62.00	49.73	49.76	49.09	59.63	11690
4	65.15	52.65	52.65	52.35	62.15	2750

Couple Position			
tube 1	bottom	side	top
tubes 2, 3, 4	bottom	bottom	bottom

Correlation of Experimental Data

Boiling coefficients were calculated from the heat removed from the circulating water, the measured temperature difference, and the area of the tubes.

The temperature difference was obtained from the measured boiling Freon temperature and the outside tube wall temperature which was computed from the measured temperature at the center of the tube wall.

Temperatures at the three points on the bottom of tubes 2, 3, and 4 differed as much as those for tube 1 with couples placed bottom, side, and top. Table 2 shows typical data for two conditions. Since no consistent trend was observed for the data, all average wall temperatures were taken as the average for three readings each on the three couples.

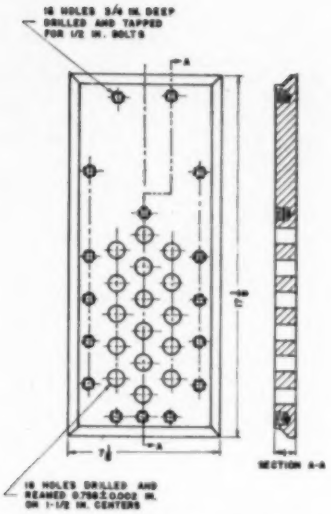

Fig. 6. Tube-sheet detail—packed end.

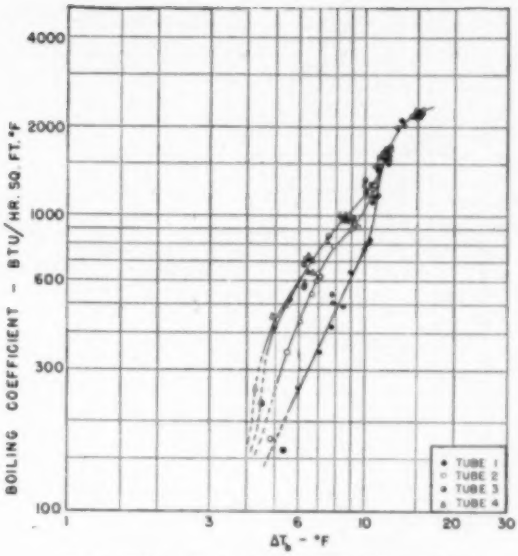

Fig. 7. Effect of tube position on boiling coefficients.

Coefficients for each tube are plotted as a function of the temperature difference across the boiling film in Figure 7. Although effects of time that the Freon had been in contact with the tube were noted, these data were all taken within a short enough period to eliminate most of this effect.

Data for the four single points at the lower end of the curves were taken while using a small ¼-ton Freon compressor. The capacity was insufficient to keep a steady state in the evaporator and consequently the Freon and water temperatures gradually increased while the data were being taken.

The influence of one tube on another is clearly shown by the spread in the coefficients obtained for different tubes. At the high temperature differences, where agitation of the liquid is relatively high, the effect of one tube on another is negligible. At medium temperature differences, the vapor rising from the bottom tube creates additional agitation around the second tube which results in a higher coefficient. The combined vapor from tube 1 and 2 agitates the liquid around tubes 3 and 4 in a similar way. No significant difference is observed between tubes 3 and 4 in this region. Apparently the effect of the agitation had reached an optimum for the tube arrangement by the time the third tube had been reached. The agitation resulting from the additional vapor reaching the fourth tube was perhaps countered by the detrimental effect of the surface being partially blanketed

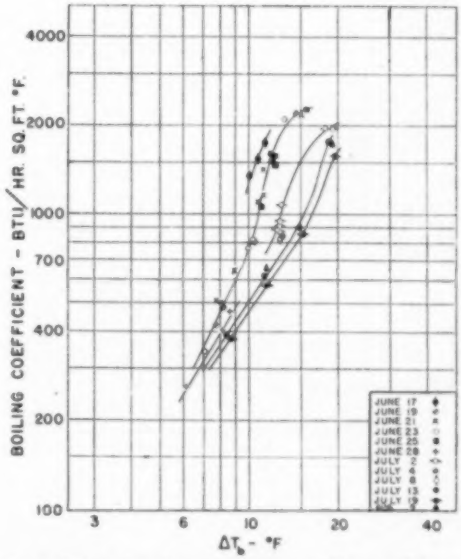

Fig. 8. Effect of surface conditions on boiling coefficients.

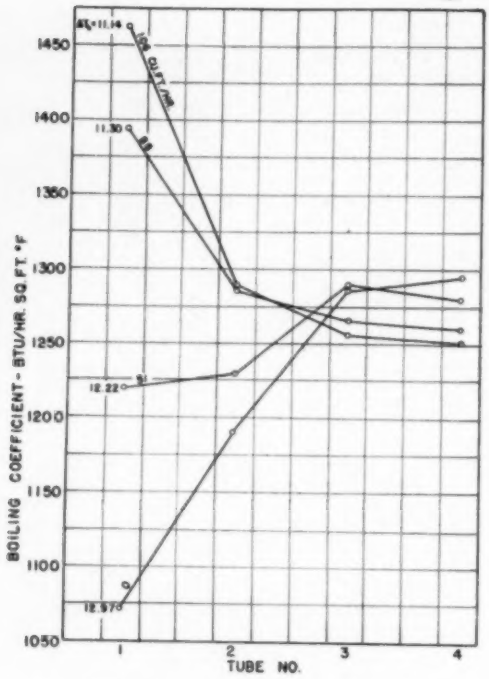

Fig. 9. Effect of vapor injection on boiling coefficients.

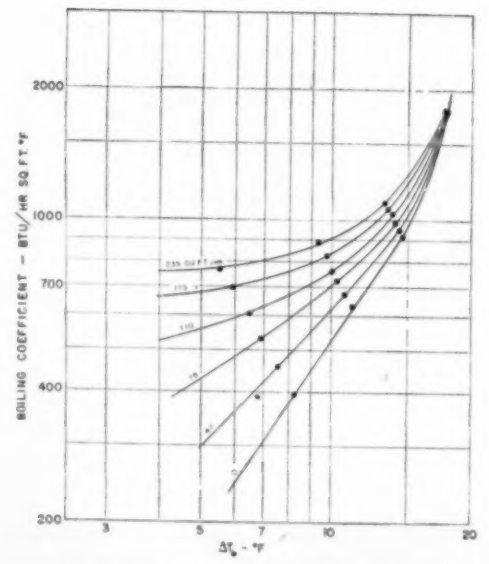

Fig. 10. Effect of vapor injection on coefficients.

off by bubbles of vapor. At the lower temperature differences, the amount of vapor rising from the bottom tube is so small that it has a diminishing influence on the coefficient for tube 2. On the other hand the combined vapors from tubes 1 and 2 are sufficient to increase the agitation around tubes 3 and 4.

At a temperature difference across the boiling film of 6° F., it may be seen that the coefficient for tube 2 is about 68% higher than for tube 1 and the coefficients for tubes 3 and 4 are about 130% higher than tube 1. It does not follow that the upper tubes in a unit transfer more heat. For example, in one run, the coefficients for tubes 2, 3, and 4 showed an increase of 32, 61, and 73% over the coefficient for tube 1. However, the boiling temperature difference decreased for each tube, with the net result that the heat flux only increased by 22, 34, and 41% respectively.

Effect of Time. After about half the data had been assembled it became apparent that the condition of the surface of the copper tubes was changing with time. This variation in the nature of the tube surface was having a pronounced effect on the coefficients as shown in Figure 8 for the bottom tube.

The first day the tubes had been in the evaporator after being cleaned with dilute cleaning solution gave the highest coefficients.

Data of Figure 7 were taken from June 19 to 25 with only a slight shift being observed during the period and are represented on Figure 8 by one curve. After 32 days of intermittent operation the coefficient no longer decreased. Later, a rise in coefficient took place while the equipment was idle and the tubes were in contact with the Freon liquid for 20 days.

The effect of time in changing the coefficients is greater at higher temperature differences than at lower temperature differences. No change in the appearance of the surface could be observed by the eye. These changes in boiling coefficient with time are in general agreement with the work of Pridgeon and Badger (*12*).

Effect of Injected Vapor. Three different sets of data were taken to study the effect of injected vapor on the coefficients for the four tubes.

Stable conditions were reached in the system and measurements made on all tubes. Vapor was then injected beneath the bundle, with the water inlet temperature, evaporating temperature, and water velocity held constant. Measurements were made again on all tubes. This process was repeated for several different vapor injection rates.

Volumes of vapor injected in each run were calculated from the data taken at the Freon orifice. Since the vapor came from the compressor it was superheated relative to the vapor in the evaporator. Each pound of injected vapor would result in slightly more than one pound of vapor generated in the evaporator because the desuperheating would evaporate some liquid. It is the actual volume of saturated vapor generated beneath the tube bundle that is reported.

Figure 9 indicates typical relative values of the boiling coefficients for the separate tubes for different gas rates. Rates of vapor injection and boiling temperature differences for the bottom tube are indicated on each curve. The boiling temperature difference was not constant but decreased from 12.97° F. at no gas flow to 11.14° F. at maximum gas flow.

The coefficient for the bottom tube is seen to have increased considerably as gas was introduced, while the coefficients for the top tubes generally decreased.

The emergent velocity of the Freon vapor from the injector tube were from 65 to 325 ft./sec. The pattern of the vapor leaving the bottom tube may have been such that the vapor either was deflected away from tubes 2, 3, and 4 or the vapor bubbles may have had a blanketing effect.

A more extensive series of data was taken to study the effect of injected vapor on the bottom tube only. Five different rates of injection were used for four different initial conditions. The inlet water temperature, Freon temperature, and water velocity used for the initial conditions were held constant for each of the five different rates of injection.

A plot of the data for these runs appears in Figure 10. The effect of the injected gas on the boiling coefficient is seen to be large at low temperature differences and to drop off to zero at higher temperature differences. This is in agreement with the previously observed behavior for the case of the four tubes in a vertical row where no difference between coefficients was observed for different tubes at high temperature differences.

Figure 11 is a plot of boiling coefficient vs. rate of injection at constant ΔT obtained by cross-plotting the data of Figure 10. Each curve at constant boiling temperature difference is apparently asymptotic to some upper limit of heat-transfer coefficient independent of vapor injection rate.

Inside Coefficients. Inside coefficients were calculated for all runs. Figure 12 is a plot of the experimental Nusselt number divided by the Prandtl number

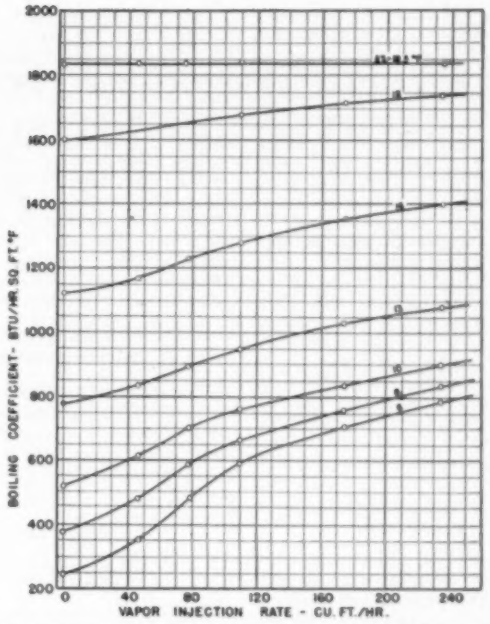

Fig. 11. Boiling coefficient as a function of vapor injection rate.

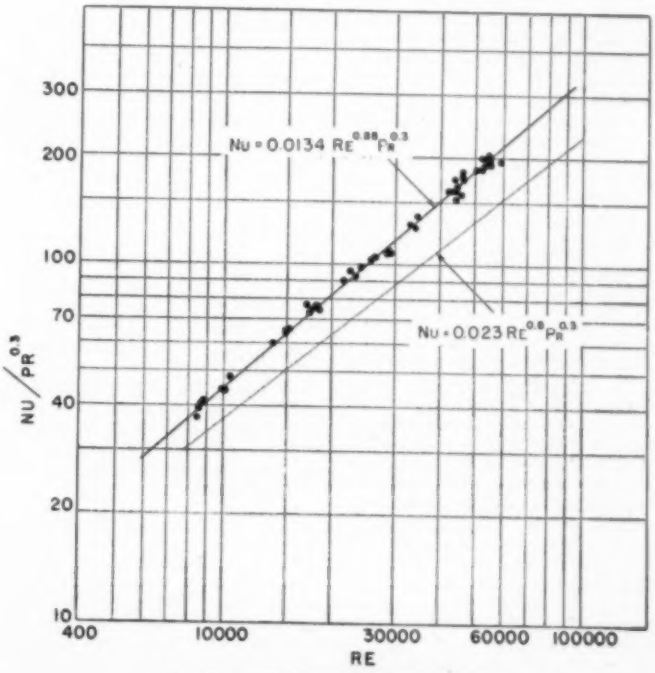

Fig. 12. Correlation of inside coefficients.

to the 0.3 power vs. the Reynolds number. The coefficients for the four tubes were averaged in making the figures.

The slope of the curve through the data in Figure 12 is 0.88. The equation for calculating the water coefficient then becomes

$$\frac{h_i D}{k} = 0.0134 \left(\frac{DV\rho}{\mu}\right)^{0.88} \left(\frac{C\mu}{k}\right)^{0.3} \quad (3)$$

A line representing the usual Equation (11) is drawn for comparison.

The unusually high power on the Reynolds number might be explained by the fact that the orifices were relatively close to the inlet of the tubes. The water leaving the orifice may have a higher degree of turbulence adjacent to the tube wall than occurs when the velocity distribution for the water depends only on mass velocity, pipe diameter, and fluid properties.

Factors Influencing Boiling Coefficients

Results of this investigation show clearly some fundamental variables that must be considered when attempting to correlate boiling coefficients. The profound change in coefficients with time has confirmed the fact that surface is a significant variable which up to this time has been denied quantitative description. It is felt that the mechanism of boiling is such that vapor generation takes place at an active center on the surface of the tube. The boiling coefficient changes as a result of various centers becoming active or inactive as the conditions change. The effect of time is to reduce the activity of all centers and hence reduce the maximum coefficient. This is in accordance with the observed downward displacement of the coefficients in Figure 8. It is believed that the effect of agitation would be relatively the same with respect to any of these displaced curves. In other words a family of curves similar to the one in Figure 10 could be obtained for any condition of the surface.

Figure 11 indicates that temperature difference and agitation by vapor movement have a degree of independence. It is believed that boiling coefficients at high temperature differences in nuclear boiling may not be attained by agitation with vapor at a lower temperature difference. This is contrary to the work of Austin for purely mechanical agitation. This work indicates that ΔT_b is a fundamental variable which affects the boiling coefficient and that it is not just a convenient measure of the state of agitation of the liquid under nuclear boiling conditions.

A significant feature that has been brought out by the data for Freon 12 boiling coefficients is that the coefficients are less than 300 B.t.u./(hr.)(sq.ft.)(° F.) at temperature differences less than 7° F. As the temperature difference between the boiling refrigerant and the fluid being cooled is reduced to improve the efficiency of the cycle, the boiling coefficients are adversely affected. With water velocities of 6 ft./sec. inside the tubes, inside coefficients would be about 1100 B.t.u./(hr.)(sq. ft.)(° F.). This ratio of inside to outside coefficients confirms that tubes with fins on the outside could be used to an advantage in water coolers (*10*).

Acknowledgment

This investigation was made possible by a Fellowship grant to the University of Michigan by the Wolverine tube division of the Calumet and Hecla Copper Co., Detroit, Mich.

Notation

h = boiling coefficient, B.t.u./(hr.)(sq.ft.)(° F.)

h_i = inside convection coefficient, B.t.u./(hr.)(sq.ft.)(° F.)

k = thermal conductivity, B.t.u./(hr.)(sq.ft.)(° F./ft.)

m = numerical constant

C = specific heat, B.t.u./(lb.)(° F.)

D = inside diameter of tube, ft.

E = numerical constant

ΔT_b = temperature drop across the boiling film, ° F.

ΔT_i = temperature drop across the inside film, ° F.

V = velocity of fluid flowing in a tube, ft./hr.

μ = viscosity, lb./(ft.)(hr.)

ρ = density, lb./cu.ft.

Discussion

A. C. Mueller (Du Pont Co., Wilmington, Del.): The vapor under the bottom tube was in terms of cubic feet. How many tubes might that flow be equivalent to? Were all these tests made at one pressure or was the pressure elevated? I noticed you had three vertical rows of tubes. Were the other two outside rows used?

D. L. Katz: We did not have any heat transfer in any other than the center row. In representing the quantity of the vapor in terms of equivalent tubes I cannot tell you how many the gas represents. I know that we did try to correlate the data on the basis of vapor emitted and Robinson, at the time, did not find any correlation that would permit him to employ vapor evolution below a tube as a variable. As I recall, the data were all taken at a range of pressures corresponding to temperatures from 32° to 70° F. Since that time we have taken a series of measurements at constant pressure. Those curves are similar to the ones I have shown you, parallel lines displaced by an order of 10% for the range of pressures I mentioned.

Anonymous: What was the size of the orifice in the tube which you used to measure your rate of flow?

D. L. Katz: As I recall, the orifice was ¼ in. in diameter and the number of diameters varied because of the fact that some of the orifices were closer to the tube than others.

Walter E. Lobo (M. W. Kellogg Co., New York, N. Y.): Do you feel that there is a practical application of your findings?

D. L. Katz: I would say that in the past we were dealing with heat transfer to boiling liquids from horizontal and vertical plates on short tubes in most cases. I would like to see data of actual boiling units that could establish what you would expect to obtain in a boiling unit. I have never seen the effect of tube bundle positions and we felt that this would help along those lines. The effect of injecting flash gas should be of interest in the refrigeration industry.

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CHEMICAL ENGINEERING IN THE FROZEN FOOD INDUSTRY

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THE subject of this paper is so broad in scope that it was decided to illustrate chemical engineering progress in the frozen food industry by reference to the production of frozen citrus concentrates. The response of the American public to these concentrates, that is, frozen concentrated orange juice, grapefruit juice, blends of orange and grapefruit, followed by grape juice, has been enthusiastic. Frozen orange-juice concentrate is playing the major role among these products of relatively high-vacuum, low-temperature processing. From a rather obscure introduction in 1946, it rose to nationwide distribution in 1947, and achieved pre-eminence in the frozen food field in 1949.

In the 1947-48 season, 2½ million concentrate gallons were produced (about 4% of the Florida orange crop). During the 1948-49 season this was increased to about 10 million gallons, and a further increase to almost 22 million concentrate gallons was reached during the 1949-50 season. It has been estimated that the production for the 1950-51 season may reach 28-30 million gallons (*4*). This will require approximately 30% of the nation's orange crop.

Historical

The success and development of frozen concentrated orange juice have been due to the initiative, research, and salesmanship, of many individuals and companies. Attempts have been made for some time to concentrate by freezing out a portion of the water from freshly expressed juice, followed by separation of the ice crystals from the solution. Both economic and technical difficulties encountered in this process, however, have almost eliminated this method from commercial practice.

Concentration by evaporation at temperatures below 100° F. to avoid impairment of natural flavor was started about 1936 (*2*). MacDowell and his associates (*1*), however, were the first to report the improvement gained by adding freshly extracted juice to a concentrate prepared by evaporation under vacuum at low temperatures. The process used today is shown schematically in Figure 1.

Process. Since the product is not pasteurized or otherwise heat-treated, the principal problem in processing becomes one of maintaining the lowest total microbial population. This is accomplished through the use of carefully selected, tree-ripened, sound fruit; also through careful supervision and control of selected chemical washes and rinses in conventional equipment. Close control of the juice extraction is also important in the operation of the processing plants. Plant sanitation similar to that employed in the dairy industry is imperative.

It will be noted that the process consists of five principal operations, namely, washing and selecting of fruit; extraction or pressing of the juice from the fruit; evaporation to 55-65° Brix; blending of the concentrated juice with a quantity of freshly extracted juice, and finally, preservation of the product by freezing. (See Fig. 1.)

The major development in the industry has centered around different types of evaporators and different methods of freezing the product. The rest of the equipment is conventional and in use in one or more other industries. Consequently this paper will be limited to a discussion of developments in these two fields of equipment design.

Evaporators

It is important that concentration of the juice be accomplished at temperatures sufficiently low to avoid impairment of the natural flavors of the juice. In actual practice vapor temperatures range from 55° F. to as high as 80° F. depending upon the type of evaporator in use.

Figure 2 is a schematic drawing of one of the first evaporators used in the concentration of citrus juices for frozen citrus concentrates. It will be noted that this is essentially a falling-film recompression evaporator with multipass circulation. Five passes are used in the later designs, however, as many as 13 and 14 were used in earlier models. This is the basic design from which later development of evaporators used in the frozen citrus concentrates

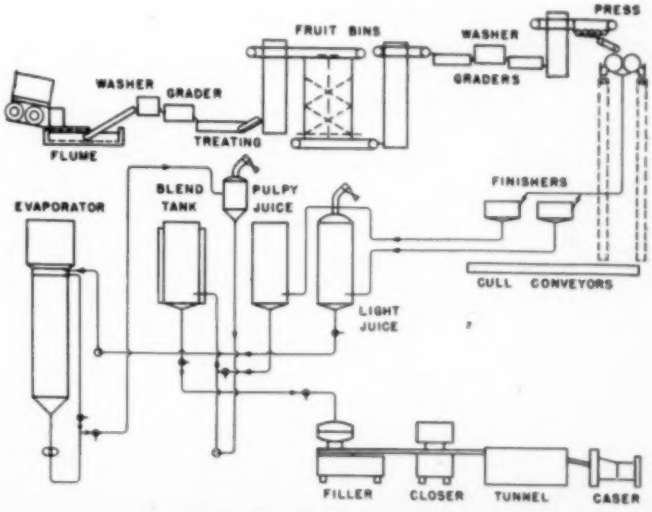


Fig. 1. Flow diagram for frozen citrus concentrates.

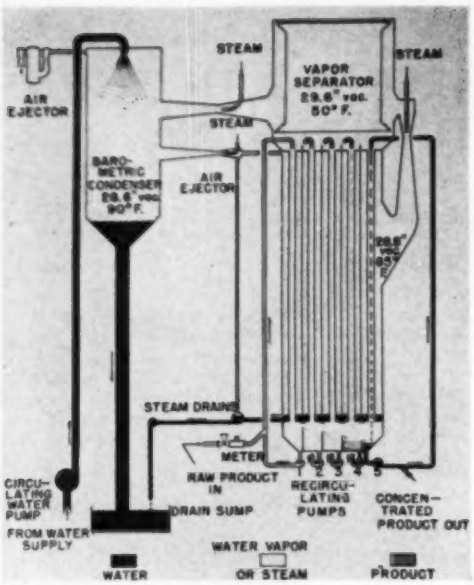


Fig. 2. Skinner evaporator.

industry has stemmed. It will be noted that in this design the vapors are recompressed to maintain a temperature of 85° F. to 90° F. surrounding the tube. Early in the development of these evaporators it was found necessary to provide a low-temperature heating medium in order to prevent the scorching of this heat-sensitive concentrate. In some of the later developments, departure has been made from the use of such low-temperature steam or recompressed vapor as a heating medium.

A diagram is shown in Figure 3 of the next evaporator that was developed for use in frozen citrus concentrates (*3*). The evaporator itself (indicated as concentrators in the diagram) is composed of 13 towers instead of three as shown. Each of these towers is 30 in. in diameter by 27 ft. in heated length, and are operated in series. Each has an effective heating area of 193 sq.ft. Here again will be noted the application of the falling film and multipass principles of evaporator design. Thirteen towers are employed in order to eliminate the necessity of recirculation within the stages. It will readily be seen that such an evaporator will require considerable floor space for its capacity output. It seems significant that only two such units were built, at least for this industry.

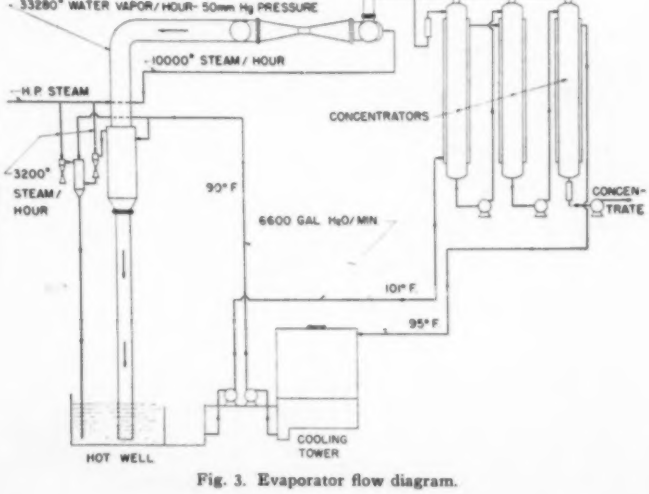


Fig. 3. Evaporator flow diagram.

One of the few applications of the heat-pump principle, first suggested by Lord Kelvin, to evaporator design is shown in Figure 4. Hot-compressed ammonia gas is supplied to the tube nest at about 110° F. Here it gives up its heat to cause boiling of the citrus juice. The partially cooled ammonia is cooled further to 45° F. and liquefied on passing through an expansion valve. The liquefied ammonia is supplied to the tubes of a vapor condenser which vaporizes the ammonia. The vaporized ammonia goes to the suction side of the compressor to start the cycle over again. Vapors from the boiling juice are separated in the vapor chamber, and then conducted to the tubular condenser, where they are condensed with the cooled liquefied ammonia. Condensate usually is sewered because it contains a small amount of entrained orange solids, so that its use in the boiler-house is not desirable. It will be noted that this system is not entirely perfect, and consequently a small secondary condenser has to be used in the system. Three units, each comprising a tube nest, a vapor separator and a vapor condenser are usually coupled together to form a falling-film three-stage evaporator assembly. However, the combination operates as a single-effect evaporator within ½ in. of the barometer.

The evaporator depicted in Figure 5 is fundamentally nothing more than the application of the recompression principle to a standard falling-film double-effect evaporator, designed to operate at liquor temperatures of about 58° F. in the second effect and about 80° F. in the first. The backward feed principle is used in this evaporator, that is, the light juice is fed into the second effect, which operates at the cooler temperature, and the concentrate is pumped out of the first effect, which operates at the higher temperature. The advantages of using the double-effect evaporator are a reduced amount of steam necessary for the evaporation, and a reduction in the amount of water for condensing the vapors.

The evaporator shown in Figure 6 is basically similar to that indicated in Figure 2. It is a three-pass single-effect recompression falling-film evaporator comprised of three separate units, each containing a tube nest, a vapor chamber and a connecting recompression jet. All three units are hooked together to operate as a single-effect evaporator. A single booster jet compresses the balance of the vapors to the pressure of the barometric condenser. Recirculation of liquor is used in each stage and is moved forward by means of overflow pipes to the next stage. These evaporators are designed to concentrate under a vapor temperature of 60° F. to 80° F., with the heating medium composed of steam plus compressed vapors supplied to the tube bundles at approximately 110° F.

Application of a triple-effect evaporator to the low-temperature concentration of citrus juices is indicated in Figure 7. This is another application of the heat-pump principle. In this case a rotary compressor is used with Freon as the heat-exchange medium. The hot compressed Freon is cooled with water which in turn is heated to about 90° F. and supplied to the tubes of the first effect of the evaporator. In giving up its heat to cause boiling in the first effect, this circulating water is cooled to approximately 80° F. and is circulated again through the hot Freon tube bundle. Since this system is not thermally perfect, a portion of the water must be taken off and further cooled in a cooling tower. The

Freon gas is further chilled by expanding into another heat exchanger, where another stream of water is cooled to 37° F. This is supplied to a barometric condenser where it condenses the vapors from the third effect of the evaporator. The temperature of the condenser downlegs or tailpipes is approximately 45° F. This water is then recirculated through the cold Freon heat exchanger and cooled again to 37° F. The cycle is then repeated. It will be noted that this design is similar to that shown in Figure 4, except that water is used as an intermediate heat-exchange medium, and the triple-effect-evaporating principle is employed instead of single effect. The original design of this evaporator used the forward feeding principle as noted in the sketch. However, it was necessary to change this to backward feed because the capacity was seriously reduced due to the high viscosity of the concentrated juice under these low third-effect temperatures. The advantages of this design are greatly reduced power requirements and water usage.

Figure 8 shows another application of the heat-pump principle to evaporators. It will be noted that this is similar to Figure 4 except that a double-effect evaporator has been employed, but that higher temperatures must be employed in one effect. This unit has the advantage, however, of requiring less energy input per thousand pounds evaporation than that of Figure 4.

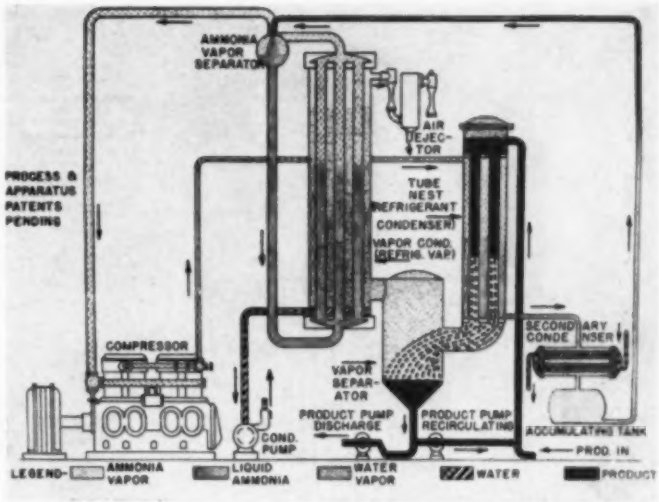


Fig. 4. Low-temperature evaporator.

Freezing Methods

One of the earliest methods of freezing the product was to freeze partially to a slush in a Votator (Fig. 9), followed by hardening in cans stored in cases in a cold room at −10° F. A Votator is comprised of three horizontal cylinders, usually about 6 in. in diameter, that are chilled by means of expanded ammonia refrigerant. The product is forced through these cylinders in series by means of a positive pressure pump of sanitary design. Inside the tubes are mounted rotating scraper blades which scrape off the ice crystals as they are formed on the tube walls, and reincorporate them in the main body of the liquid. This process is repeated as the product moves through the three cylinders in series until it is discharged from the third one in the form of a semisolid slush. The product is then put into cans, sealed, cased, and put into the cold storage room.

The principal disadvantage of this system was that the product was not hardened in days, or even weeks, where it was tightly stacked in piles in the warehouse. In order to accomplish hardening in a shorter time it was necessary to "open-pile" in the warehouse, and this resulted in a loss of much valuable cold storage space. In order to overcome this disadvantage one plant stacked the cans that had been slush-filled in racks in the hardening room. In this way, hardening was accomplished in four to five hours. The cans were then conveyed to the caser, and stored in the cold storage warehouse. Neither of these methods is now in use. The sealed cans are now put through a secondary freezing unit and frozen solid before they are packed in cases and put into cold storage.

Figure 10 is a cutaway view of a cold air blast tunnel applied to this industry in an effort to reduce the hardening or freezing time of the citrus concentrates. The filled cans were stacked on trays, and then conveyed by means of a carriage to a compartment that was sealed off from the main air blast. The carriage was then removed, and the main door closed, and an electrically operated conveyor system advanced this newly filled compartment one position (to the right in the view shown). That brought a compartment containing cans of frozen concentrate into the air-sealed chamber. The door was then opened and by means of a carriage the trays containing the cans of frozen concentrate were removed and the operation was completed. There were 22 compartments in one of these units, and the holding time was 1½ to 2 hrs., during which time the contents of the cans were frozen and the temperature reduced to about 0° F. The air left the blowers at temperatures of −27° F. to −35° F. and was uniformly distributed over one set of compartments

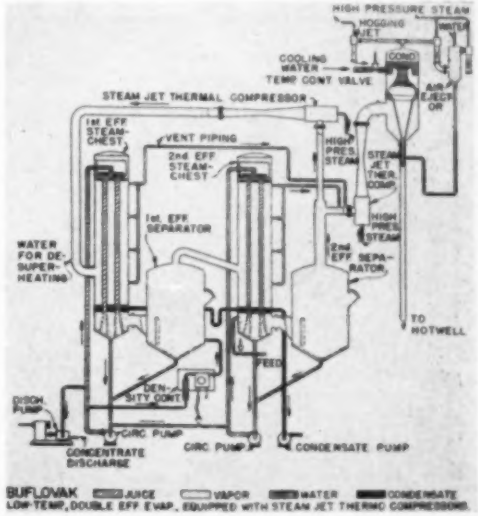


Fig. 5.

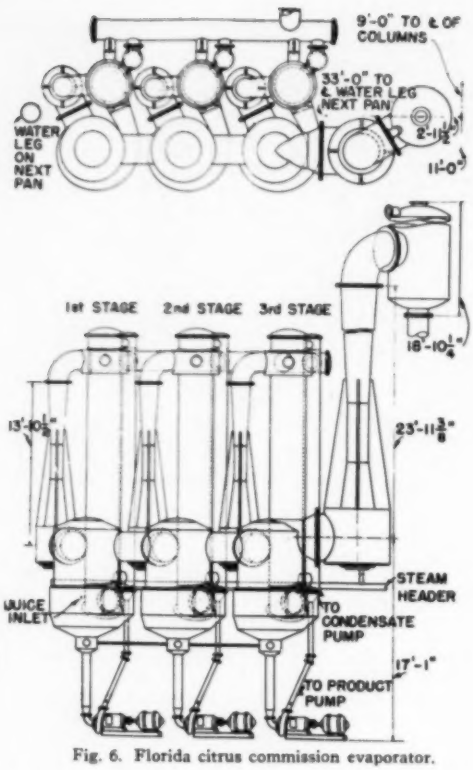


Fig. 6. Florida citrus commission evaporator.

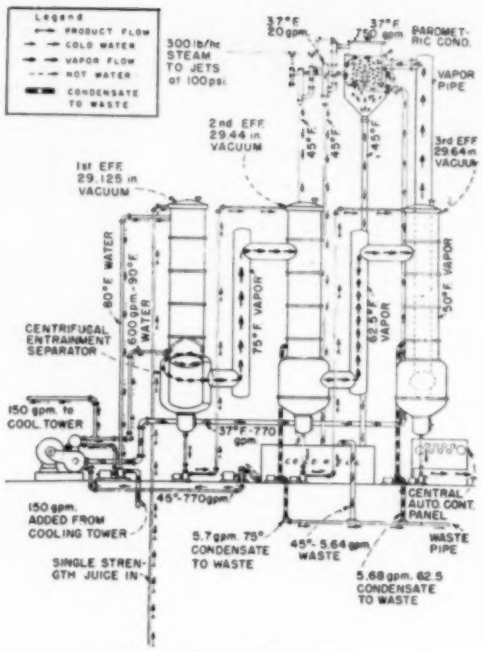
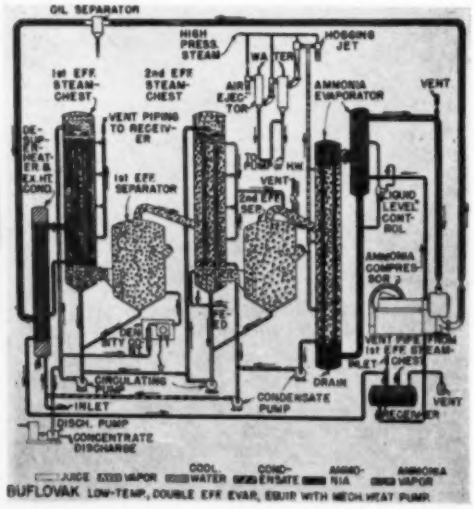


Fig. 7. Howard evaporator.

by means of multilouvered openings. It then passed through another set of compartments to the suction side of the blowers and was passed over the cooling coils to be cooled again. It will be noted that countercurrent air flow was used in this operation, inasmuch as the warm cans moved to the right and followed a path similar to a race-track as they moved around to the left, where the coldest air was applied. Though this system worked satisfactorily, there was too much labor involved, and now it is no longer in use. In actual operation it took 10 to 12 men to operate two units. The problem was principally in the loading and unloading of the trays.

Figure 11 shows the next development in the freezing of citrus concentrates. This is a continuous air-blast tunnel operated at temperatures between −30° F. and −40° F. Cans are fed at the near end at temperatures ranging from 40° F. where no Votator is used, to 18° F. to 20° F. when used in conjunction with a Votator. The cans are removed from the far end of the tunnel about an hour or an hour and a half later, at temperatures of 0° F. or below. A continuous mat belt conveyor is used to transport the cans through the tunnel. Air at −30° F. to −40° F. is blown down between the cans and recirculated over the refrigerating coils. A number of units similar to this one are in use throughout the industry.

The principal advantage of these units is that they require only one man at each end for efficient operation. Several plants operate such units with virtually no attention whatsoever. However, usually in such cases when



BUFLOVAK LOW-TEMP., DOUBLE EFF EVAP., EQUIP WITH MECH. HEAT PUMP.

Fig. 8.

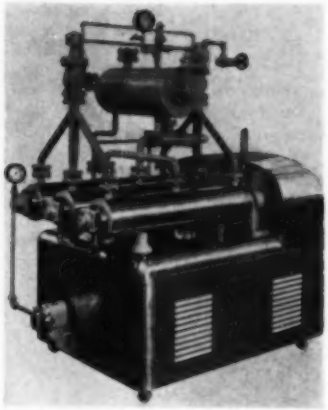


Fig. 9. Girdler votator.

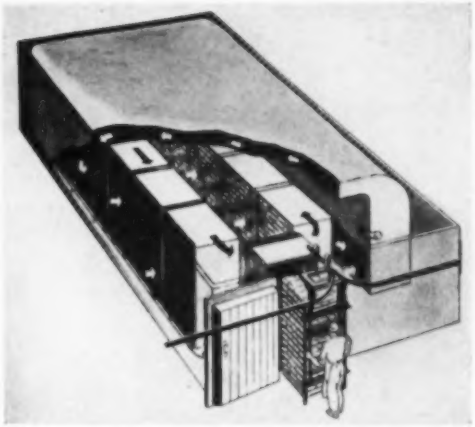


Fig. 10. Salem blast freezer.

the feed is interrupted for one reason or another, there is an empty place on the belt, which runs continuously, and results in poor freezing because of non-uniform air flow through the conveyor.

Another method of freezing citrus concentrates is shown in Figure 12. It is composed of an insulated box housing six tubes, cross sections of which are shown in the lower right-hand corner of the sketch. In the bottom of the tubes is a rotating bar which imparts rotating motion to the cans as they are pushed through the tubes. Inside the tubes is a perforated liner that distributes alcohol solution at about −30° F. in such a manner as to bathe the cans as they progress through the tubes. A heat exchanger is used to chill the alcohol solution by means of expanded ammonia or other refrigerant.

Figure 13 is a photograph of one of the latest pieces of equipment to be adapted for freezing citrus concentrates. It has been widely used in pasteurization processes. It is composed of a conveyor bed above which is mounted a series of sprays which distribute alcohol solution at about −30° F. over the cans as they progress through the unit. The conveyor bed is composed of a series of rods or bars, each alternate one being stationary. The rest of the bars are actuated by eccentrics in such a way that they lift up and in so doing pick up the cans, then move forward, and are lowered below the level of the stationary bars. Then they return to their former position. When the movable bars reach a point below the stationary bars the cans are deposited on the latter, and consequently this motion moves the entire lot of cans forward. In this way the cans are conveyed through the tunnel, meanwhile being bathed in cold alcohol solution. With this equipment the manufacturer claims that the center temperature of a 6-ounce can of concentrate can be reduced from 20° F. to 0° F. in 23½ min.

Another piece of equipment is shown in Figure 14. It has been widely used in other industries, and has been adapted more recently to the needs of this industry. This equipment was designed and used entirely, up until recently, for cooking canned fruits and vegetables. However, within the last two years it has been modified somewhat, and is now

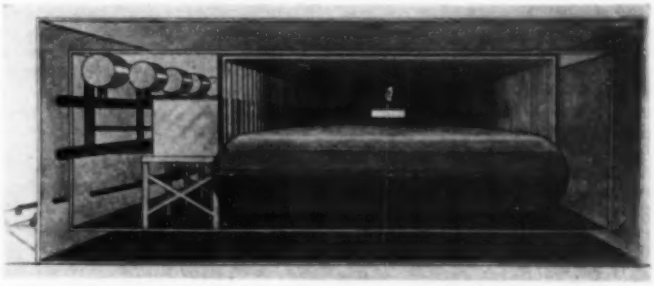


Fig. 11. Skinner freezing tunnel.

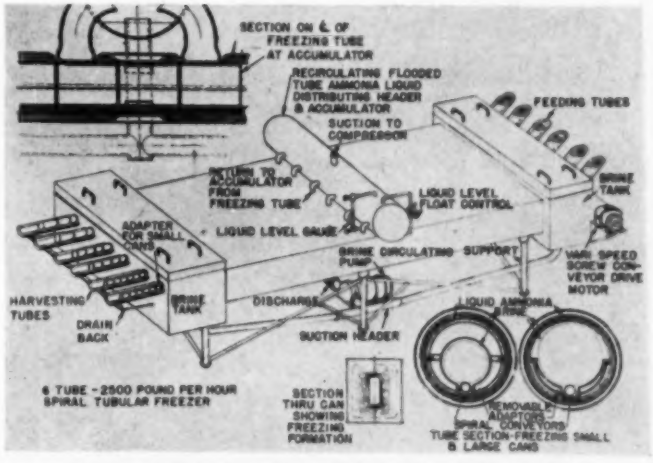

SECTION ON ℄ OF FREEZING TUBE AT ACCUMULATOR
RECIRCULATING FLOODED TUBE AMMONIA LIQUID DISTRIBUTING HEADER & ACCUMULATOR
FEEDING TUBES
SUCTION TO COMPRESSOR
RETURN TO ACCUMULATOR FROM FREEZING TUBE
LIQUID LEVEL FLOAT CONTROL
BRINE TANK
ADAPTER FOR SMALL CANS
LIQUID LEVEL GAUGE
BRINE CIRCULATING PUMP
SUPPORT
VARI SPEED SCREW CONVEYOR DRIVE MOTOR
HARVESTING TUBES
BRINE TANK
DISCHARGE
LIQUID AMMONIA
DRAIN BACK
SUCTION HEADER
6 TUBE - 2500 POUND PER HOUR SPIRAL TUBULAR FREEZER
SECTION THRU CAN SHOWING FREEZING FORMATION
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Fig. 12. Diagram showing construction and operating details of Finnegan spiral tubular freezer.

Fig. 13. Vortex freezer.

used in several plants for freezing citrus concentrates. Inside the shell is mounted a reel supported by spider castings. The reel is of the drum type with the center section closed against liquid. This construction allows a 40% reduction in the volume of alcohol solution which at −30° F. is usually used as the cooling liquid. This enters through a large circular manifold around the center of the shell. The liquid is evenly distributed to the reel through a series of holes between spiral tees. Filled cans are delivered to the feed turret by means of an elevator or conveyor, and thence from the turret to the reel. As the spiral reel revolves, the cans are rolled and moved through the shell. A can extractor is provided at the discharge end of the freezer. The cooling liquid flows both ways to the end of the shell and out of the top to the storage tank. Cans are completely submerged while in the freezer.

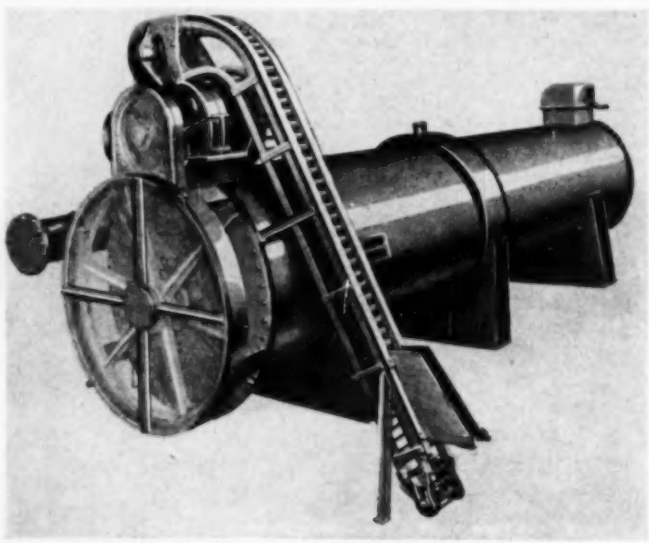


Fig. 14. FMC continuous round shell freezer.

With this equipment it is claimed that the contents of a 6-ounce can of citrus concentrate can be reduced from 40° F. to 0° F. in less than 45 min. It is also claimed that the unit is completely automatic and requires comparatively small space.

Acknowledgment

The author wishes to acknowledge the cooperation of a number of equipment manufacturers who so graciously supplied photographs, bulletins, and other literature from which most of the illustrations used in this paper were taken.

Literature Cited

1. MacDowell, L. G., Moore, E. L., and Atkins, C. D., U. S. Patent No. 2,453,109 (Nov. 9, 1948).
2. Rector, T. A., *Chem. Eng. News*, **28**, 242 (1950).
3. Schwarz, H. W., and Penn, F. E., *Ind. Eng. Chem.*, **40**, 5, 938 (1948).
4. Special Report, *Quick Frozen Foods*, p. 4 (1949).

Discussion

Anonymous: What constitutes the major portion of processing problems for frozen concentrates? Freezing or evaporating?

V. C. Praschan: I think the principal problem has been in evaporation. However, fortunately, considerable work had been done with low temperature concentration prior to the advent of frozen citrus concentrates. The process met success principally because of overconcentration and the blendback of freshly extracted juice. This supplied some volatile esters and flavors which the concentration operation removed. Freezing methods presented a problem which was handled and while successful, presented an economic problem. Concentrates were hardened in the hardening room, but this operation took time and storage and −10° F. is expensive. Development then came in tunnel-type freezers, in which labor is considerably reduced, thus reducing costs.

R. W. Callahan (General Mills., Inc., Minneapolis, Minn.): Has there been any work on fractionating vapor from evaporation for recovering some volatile flavor esters as is done with apple juice?

V. C. Praschan: Considerable work has been and is being done without too much success to date. Many times the resulting product has been reported to taste more like apple or pineapple than it does like orange.

R. W. Callahan: What is the order of magnitude of over-all heat-transfer coefficient in juice evaporators?

V. C. Praschan: It is approximately 100 B.t.u./(sq.ft.)(hr.)(°F.) of temperature difference.

K. C. MO.

Official opening is symbolized as T. H. Chilton, President, A.I.Ch.E., pins on badge.

KANSAS CITY proved its attraction as a chemical center for members of the A.I.Ch.E. last month when well over 700 chemical engineers registered for the Institute's second meeting in 1951. The tide of registrants made this the third largest meeting, aside from annual meetings, in Institute history by just barely nosing out the San Francisco meeting in 1946 which was previously in third place. A particularly full program had been planned by the local and national committees, attracting chemical engineers from all over the United States to supplement local registration.

The meeting got under way to a flying start at a mixer on Sunday evening at which civic leaders of Kansas City were present to meet, and discuss the potential that chemical engineering has for the area.

Shelby A. Miller, associate professor of chemical engineering at the University of Kansas, Lawrence, Kan., and chairman of the Kansas City Section, gave a welcoming address on Monday and pointed out during his talk something about the natural assets of the area. During the course of his remarks he said, "Kansas City is a point of intersection of East and West, and at the same time a point of intersection of several important areas in our economy; an intersection of the vast areas of mineral wealth and mining; petroleum wealth, its products and refining; cereal wealth and milling; general manufacturing endeavor to the East; animal wealth and animal by-products, and product industries which are based on it. He continued:

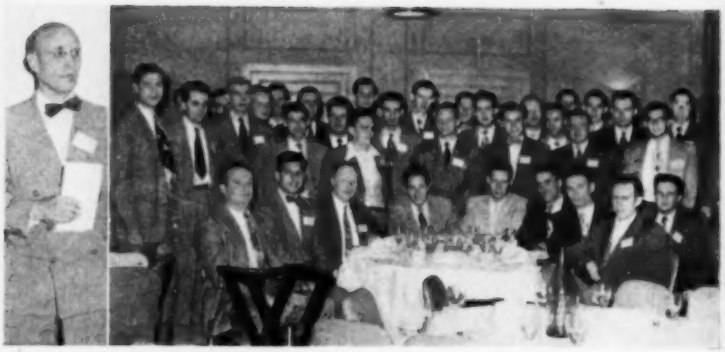
These various areas literally intercept at metropolitan Kansas City. The fact that they do has impacted this community and that impact has very considerably forged our economy as it is today. That forging is still going on. The industry of the community has gradually shifted from one which first served the needs of people working in these crudely extractive industries, and has shifted to industries serving the needs of people working in extractive industries which are of a more refined and secondary nature. And finally, relatively recently as history goes at least, it has taken on the complexion of a bona fide processing and chemical manufacturing industry.

Three nontechnical events held the spotlight outside the program of technical papers. The first was a symposium on Safety in Chemical Plant Operations under the direction of Mathew M. Braidech, research director of the National Board of Fire Underwriters, New York. The second was five "bull sessions" held Monday evening, and a sixth "bull session" on Ammonia Synthesis held Wednesday evening after the formal meeting was technically over.

John B. Rush, Phillips Oil Co. and registration committeeman, answers a question, while L. E. Colburn, chairman (right), ponders a knotty registration problem.

Executive Committee chairman and Mrs. C. W. Nofsinger look out over the throngs attending the opening night buffet, "Kansas City Greets You."

Publicity Committee members prepare press releases, while their chairman telephones a newspaper. Left to right: Willis Hart, Thompson Hayward Chemical Co.; Eleanor Boehmer, Standard Oil (Ind.); Virginia Siddall and chairman, L. S. DeAtley, of the Thompson Hayward Chemical Co.



H. Dayton Wilde was speaker at the Student Breakfast. Largest contingent of chemical engineering students were the 35 above from the Missouri School of Mines and Metallurgy, Rolla, Mo., brought by their student chapter counselor, F. H. Conrad (third from left, seated).

Speakers at the symposium on "The Effect of Company Finances on Engineering Expansion." John Miller, Spencer Chemical Co., Chet Crawford, Phillips Petroleum Corp.; Jack Riley, Spencer Chemical Co., Sam Nevins, Mathieson Chemical Co., Loren Scoville, Jefferson Chemical Co.

One of the novel features was provided by the third nontechnical session —a symposium originally titled "The Effect of Company Finances on Engineering Expansion." Actually the symposium took the form of a stockholders' meeting with every chemical engineer an active participant through the medium of a stock certificate verifying him an owner of 100 shares in the mythical Apex Petro-Sulphur Co. John R. Riley, Jr., vice-president of the Spencer Chemical Co., Kansas City, Mo., presided at the stockholders' meeting. Other "Members of the Administrative Board" were—John P. Miller, vice-president and treasurer; C. C. Crawford, vice-president in charge of research and development; S. L. Nevins, vice-president in charge of sales; L. P. Scoville, vice-president in charge of operations.

The position of the hypothetical company was first outlined by its president, John R. Riley, Jr. He said the company had as assets natural gas properties, a gas-gathering system and a natural gasoline plant. Extensive drilling yielded further gas supplies that contained hydrogen sulfide, and to remove this gas in order to make the products salable, the company also had a scrubbing plant. The H_2S removed by this operation was at present being burned as boiler fuel. The chief products of the company, sale-wise, were butane, natural gasoline and gas. The stockholders were being asked to vote on their directors' plan to produce elemental sulfur from the hydrogen sulfide.

Three courses were put to the "stockholders" for decision: First, the production and sales of sulfur by the company; second, the sale of hydrogen sulfide to an outside company which would take over the responsibilities of building and

(*More Pictures on page 20.*
Story on page 22)

▲ A portion of the bull session on "What Changes Can the Engineering College Make In Its Curriculum to Help Graduates Most?"

A cocktail party preceded the banquet.

H. A. Hopmann, Plant Trips chairman, directs engineers onto bus for a scheduled visit. Trips to plants in the KC area were popular, usually sold out at time of registration. ▼

C. G. Kirkbride, A. G. Parker, I. E. Miller at Public Relations Committee breakfast.

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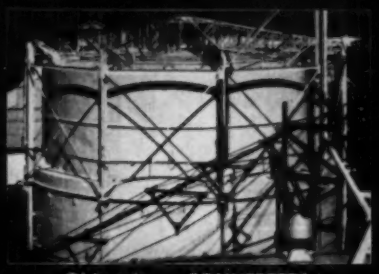

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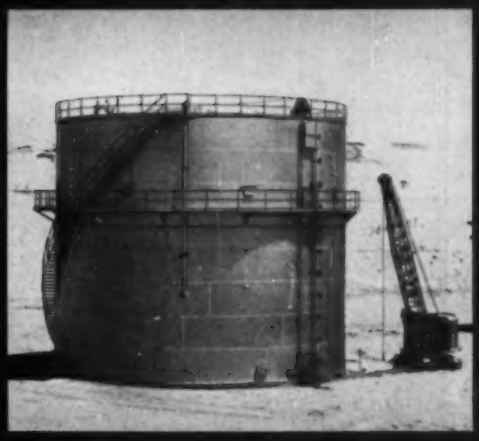

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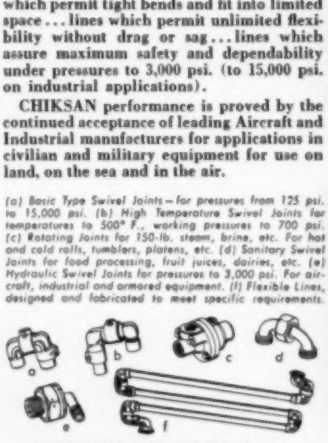

2 Brake line installation on torque link in aircraft brake system.

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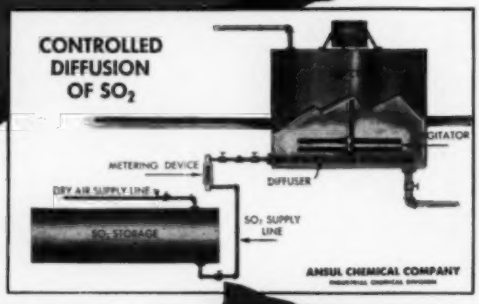

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operating a sulfur plant, and selling the sulfur; the third alternative was to do nothing.

The financial position of the company was first examined by the treasurer John P. Miller, who showed that the earnings of the company and the profit had been satisfactory for its five years of existence. Technical details of the process were explained by C. C. Crawford and L. P. Scoville.

Crawford explained the process essentially was to process the gas through a Girdler amine treater which after stripping gave a concentration of 90% H_2S. This gas could then be catalytically converted to sulfur, the total conversion being in the order of 90%; the final cleanup of the gases being taken care of by a scrubber and an incinerator.

The case for selling elemental sulfur instead of sulfuric acid was then presented to the stockholders by Nevins who made a complete market survey report of the possibilities for both products. After discussing the technical details of the process, the treasurer of the company again reported, and stated that the best method of financing the project would be to sell a 4% issue of debenture bonds totaling $1,800,000 over a 15-year term, and to pay the mortgage note.

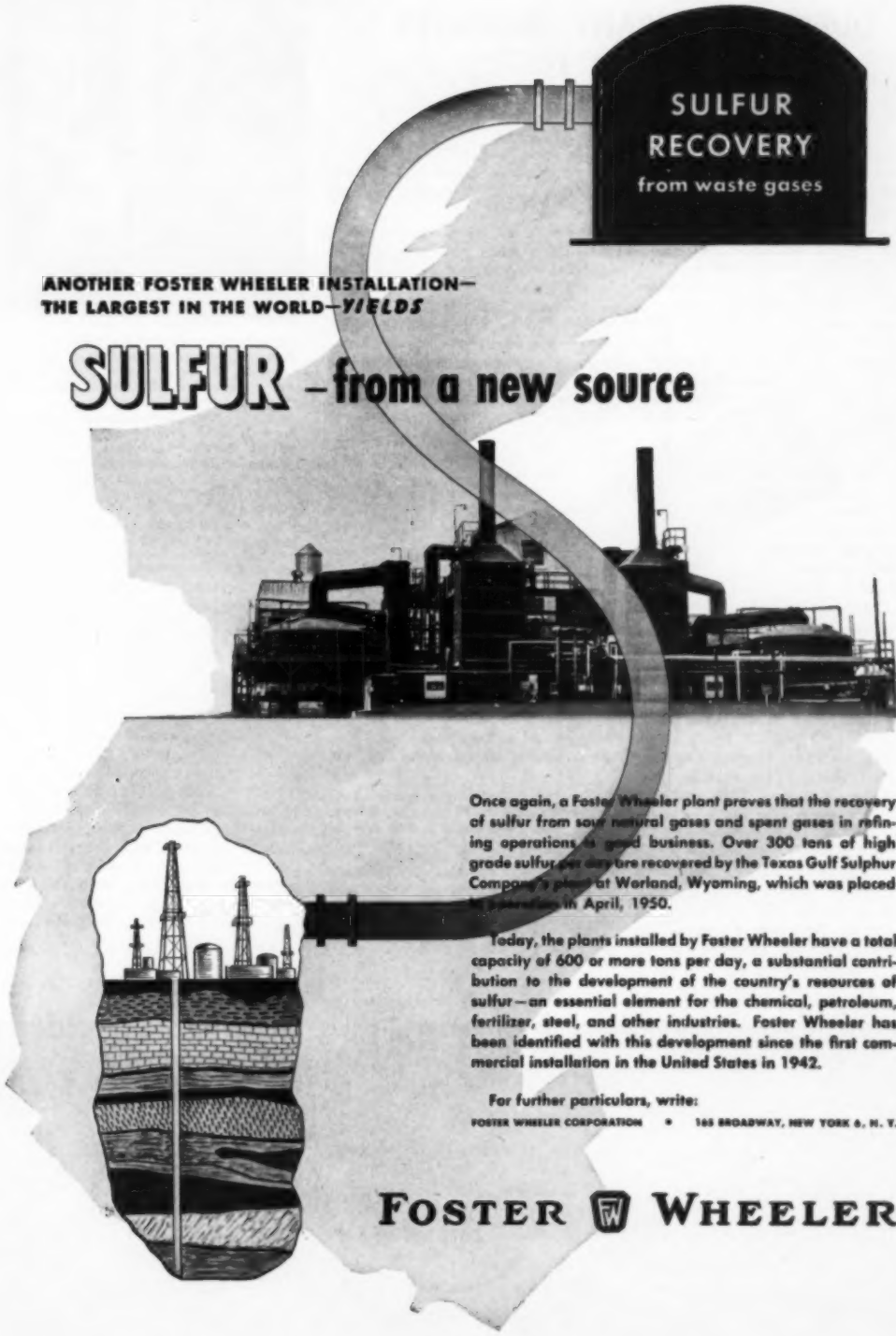
All in all the questions turned in by the audience were orderly and mild, and ultimately those present voted to approve the production of elemental sulfur by a 12 to 1 vote.

Best Presentation

The award usually made at meetings for the best presentation had to recognize more than one author, in the opinion of the judging committee. There was a four-way tie for first place and those who were judged best by the committee were J. Mauk Smith, associate professor of chemical engineering, Purdue University, Lafayette, Ind., for his paper on "Heat and Mass Transfer in Fixed Bed Reactors"; Robert R. White, professor of chemical engineering, University of Michigan, Ann Arbor, Mich., who presented a talk on "The Rate of Formation of Methane from Carbon Monoxide and Hydrogen with a Nickel Catalyst at Elevated Pressure"; Robert H. Elkins, Great Lakes Carbon Corp., Chicago, Ill., who covered, "Sulfur from Hydrogen Sulfide"; and D. M. Little, Phillips Petroleum Co., Bartlesville, Okla., for his description of "Visbreaking of a High Vacuum Petroleum Residuum."

The certificates for the presentation will be given, as is usually the case, at some future meeting of the local section of which the award winner is a member.

The judging committee was headed by George Martin Brown of Northwestern University as chairman.



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DUPONT COMPANY DEDICATES ADDITION TO EXPERIMENTAL STATION

A $30,000,000 addition to the experimental station of E. I. du Pont de Nemours & Co., Inc., at Wilmington, Del., was dedicated last month, with an inspection tour of the new buildings and a special dinner at which James B. Conant, president of Harvard University, and Crawford H. Greenewalt, president of the Du Pont Co., spoke.

The new campus-style research addition of 19 buildings does not signal a more intense research program on the part of the company and the research budget will be of the same order, company spokesmen revealed. The facilities represent rather, they said, a move into better and more efficient quarters, as well as centralization of some of the company's research activities.

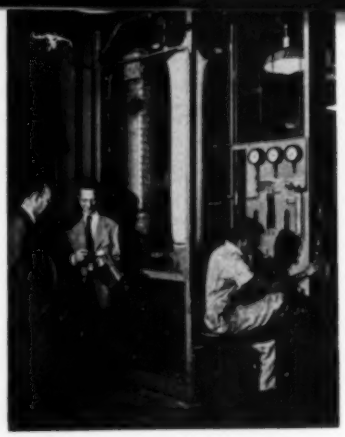
Other speakers at the dedication ceremonies were Granville M. Read, chief engineer of the Du Pont Co., and Elmer K. Bolton, director of the chemical department.

Mr. Read said that the present site of the new addition was formerly a golf course for company employees. The addition is located adjacent to the older experimental station on the banks of the Brandywine, which has been a site of the Du Pont research activities since 1903.

The statistics of the addition, given by Mr. Read, is that the "new building area comprises some 50 acres with nineteen buildings, of which nine are laboratories. The total floor area is 630,000 sq.ft. There are 158 separate laboratory units. Buildings contain 35,000 cu.yd. of concrete, 5,000,000 bricks, 1,125,000 tiles, 825 tons of granite, 970 tons of limestone masonry, 5000 tons of steel, . . . and 10,000 personal opinions." The project cost some $30,000,000, and a most notable achievement in Mr. Read's opinion is that it was built within the appropriated money.

The facts and reasoning which led up to the campus type of installation were outlined by Mr. Read as stemming directly from the organizational structure of the Du Pont Co.: "The Du Pont Company has ten manufacturing departments," Mr. Read said, "and when it comes to research, each is responsible for its own. The first plan of the new research station was to build a large, consolidated laboratory building in which all the scientific laboratories would be grouped with the semi-works and service facilities in buildings nearby. Since this was in fundamental clash with the Du Pont philosophy that each manufacturing department was an organizational unit, deciding its own operating policy, the campus-type plan was studied which specified a group of related buildings served by centrally located, general facilities. This plan won out because it made it possible for the participating departments to be free to design for their specific needs. The campus-type design provided sufficient building area for the need of each department and allowed room for its future expansion. Mr. Read stated further:

The concept of autonomy is preserved and yet group association of scientists is maintained. The main buildings are laid out around a quadrangle which permits all buildings to be readily extended outward from the center. The design of each building is fashioned to meet its research requirements. The rayon pioneering building, for example, takes the shape of a large U because of the central importance of its semi-wroks. Grasselli Chemicals, on the other hand, becomes two separate buildings; its semi-works accepts the freedom of a separate building because it need be less intimate with the laboratories; polychemicals combines both ideas, having both ideas, having both integral and separate semi-works; the chemicals department chose its location closer to the older portion of the experimental station in order to maintain close liaison with its other facilities.

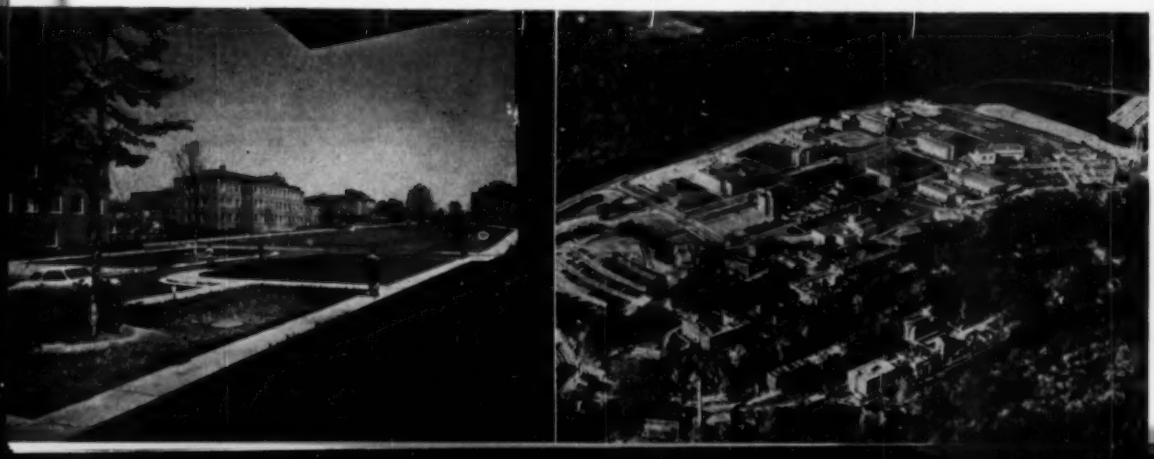


Typical of research setups in the chemical engineering section of the Engineering Research Laboratory is this experimental spray drier.

E. K. Bolton described the research facilities and the history, stating that the first Du Pont research laboratory was established in 1902, the equipment consisting of two small cases of glassware, a few chemical samples and a microscope. The experimental station was situated on the outskirts of Wilmington, on the site of the early black powder plants of the company itself and covers an area of more than 90 acres representing an investment of approximately $40,000,000. "The population," said Dr. Bolton, "now includes more than 800 technically trained men in research, or 45% of the total Du Pont research staff. These research workers are supported by a non-technical organ-

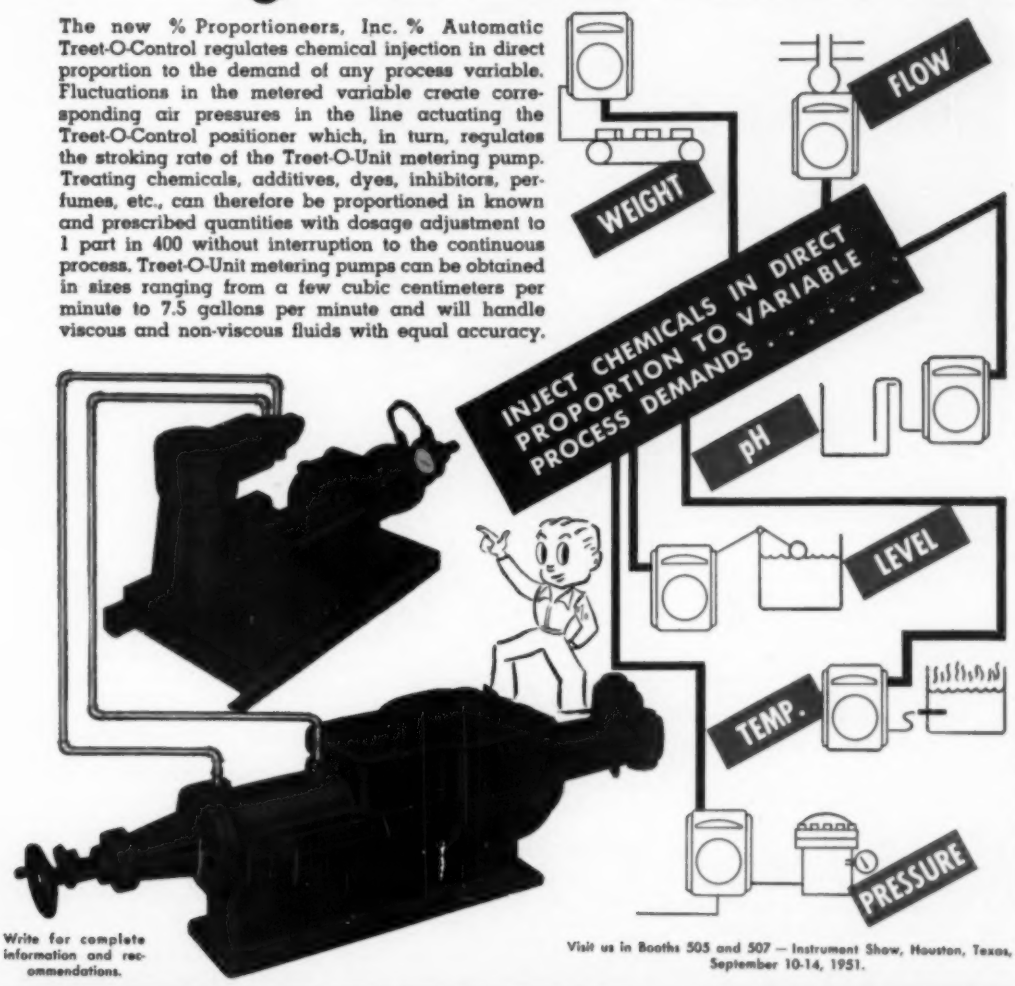
(*Continued on page 32*)

Campus-style research addition (left) and aerial view (right) of Du Pont Experimental Station.



Automatic Control FOR METERING PROCESS CHEMICALS

The new % Proportioneers, Inc. % Automatic Treet-O-Control regulates chemical injection in direct proportion to the demand of any process variable. Fluctuations in the metered variable create corresponding air pressures in the line actuating the Treet-O-Control positioner which, in turn, regulates the stroking rate of the Treet-O-Unit metering pump. Treating chemicals, additives, dyes, inhibitors, perfumes, etc., can therefore be proportioned in known and prescribed quantities with dosage adjustment to 1 part in 400 without interruption to the continuous process. Treet-O-Unit metering pumps can be obtained in sizes ranging from a few cubic centimeters per minute to 7.5 gallons per minute and will handle viscous and non-viscous fluids with equal accuracy.



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Technical service representatives in principal cities of the United States, Canada, Mexico and other foreign countries.

A new nitrogenous fertilizer plant near Mexico City was recently completed by Chemical Construction Corp. for Guanos y Fertilizantes, S.A. The huge installation includes three different, complete plants—a synthetic ammonia unit (shown above with circulator), an outdoor contact sulfuric acid plant, and an ammonium sulfate plant. Design includes equipment for power and process steam, electric generating equipment, deep well water pumps within the works, and other general facilities. According to the operators, 70,000 tons of low-cost ammonium sulfate per year will be produced for soil improvement in Mexico. The basic raw material will be natural gas.

NEW A.S.A. LIST

Ninety-nine new and revised American Standards are listed for the first time in the latest edition of the Price List of American Standards just published by the American Standards Association.

This list contains more than 1180 standard specifications, methods of test, and symbols and abbreviations in civil engineering and construction, mechanical engineering, electrical engineering, safety codes, ferrous and nonferrous materials and metallurgy, rubber, textiles, mining, pulp and paper, photography, motion pictures, and gas burning appliances.

The new list offers a complete set of all American Standards at $280 and a complete set of all American Safety Standards at $40.

The 26-page list of American Standards (May 1951) can be obtained from the American Standards Association, 70 East 45 Street, New York 17, N. Y., without charge.

STUDENTS TO TRAIN AT REACTOR TECH. SCHOOL

Representatives of 22 United States industrial firms will acquire specialized training in nuclear engineering at the Oak Ridge School of Reactor Technology during the 1951-52 term beginning in September. Of a total of 75 students who will attend the 12-month term, 24 candidates are sponsored by the industrial firms and 8 by Government agencies. The remaining 43 are recent college graduates selected primarily on the basis of their potential contribution to reactor development phases of the national atomic energy program.

The School of Reactor Technology was established in March, 1950, at the Oak Ridge National Laboratory to train engineers and scientists in the field of reactor technology. The industrial and governmental trainees will be paid by their employers during the training period. Recent college graduates will be considered student employees of ORNL during the training. At the end of the year this group may become available for employment by AEC, its contractors, or other organizations interested in reactor development.

COMBUSTION MANUAL NOW AVAILABLE

Faculty members in engineering, metallurgical, and mechanical departments may obtain a copy of "Fuel Oil and Its Combustion," from the North American Manufacturing Co. This 35-page book covers crude oil constituents and classifications, crude-oil processing, properties of fuel oils, fuel-oil combustion, plus an Appendix giving calculations on heating values, air requirements, available heat, etc.

The book, first issued in 1943, is now being made available without charge by the company. Address it at 4455 East 71st St., Cleveland 5, Ohio.

OFFICERS ELECTED BY ENG. INST. OF CANADA

New officers of the Engineering Institute of Canada were elected at the 65th annual banquet of the Institute held in the Mount Royal Hotel, Montreal, May 11, 1951, at the conclusion of a three-day professional meeting. They are: Ira P. Macnab, general manager, Halifax Public Service Commission, president, and J. W. Sanger, Winnipeg, Man.; C. G. R. Armstrong, Windsor, Ont., and J. B. Stirling, Montreal, Que., vice-presidents.

Councillors of the various branches were also elected at this meeting.

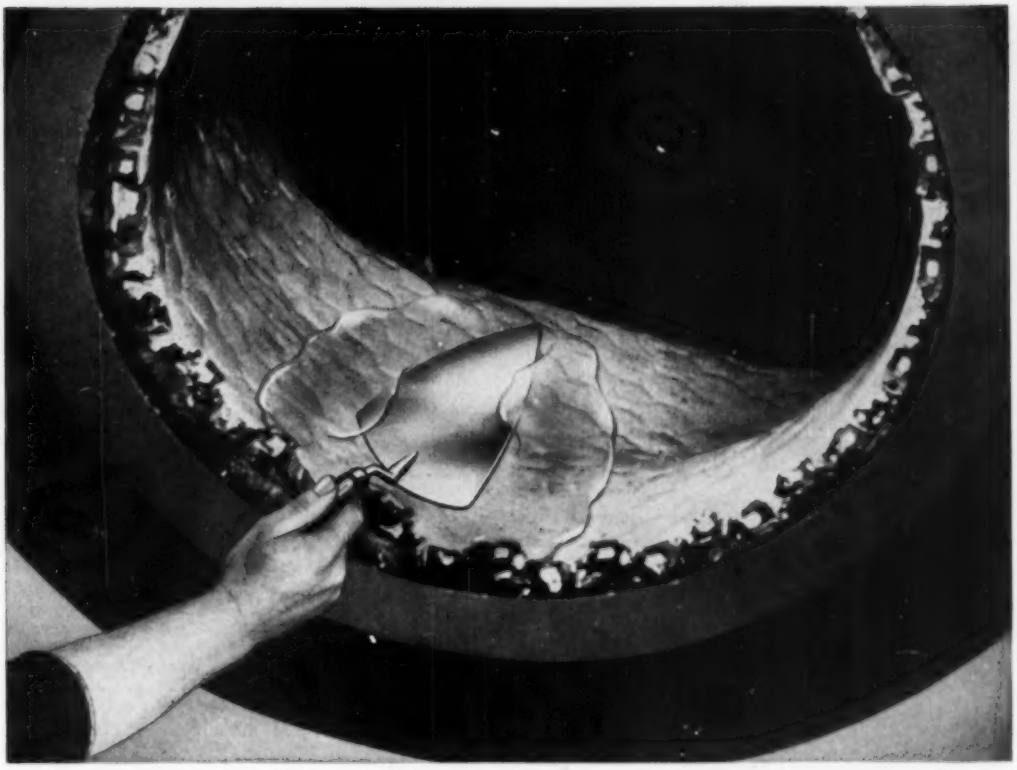
COKE FOR DEFENSE VITAL—SCHLUETER

The importance of the coke and coal chemicals industry to the national economy and national defense was pointed up by L. A. Schlueter, chief, aromatic chemicals section, chemical division, National Production Authority, Washington, D. C. Speaking before the regional meeting of American Coke & Coal Chemicals Institute in Rye, N. Y., May 7, 1951, he stated that in the past the large advances in the use of coal chemicals have been during periods of emergencies. Prior to World War I the requirements were small. During the period between World War I and World War II the aromatic chemical industry settled down to a gradual increasing growth along with much research and development work in new products. Shortly there was an excess productive capacity for most products and necessary raw materials.

Then in 1940 this country was using about 40,000,000 gal./year of benzene for chemical purposes; subsequently production amounted to 175,000,000 gal./year and imports were close to another 50,000,000 to take care of synthetic rubber, phenol, aniline, aviation gasoline, etc., for the war effort. The magnitude of growth during the last emergency is evidenced not only in benzene but in phenol production, phthalic anhydride and styrene.

Referring to benzene specifically, Mr. Schlueter said that a recent task group estimated benzene requirements for the next five years under a mobilization program and for comparison included their estimate of demand under normal peacetime economy. For 1955 the normal would be 315,000,000 gal. and for mobilization 411,000,000. Current availability from coke oven light oil, petroleum sources and imported benzol amounts to 230,000,000 gal./year.

In conclusion Mr. Schlueter maintained that the future demand for coal chemicals is assured.



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In addition, when you use Penchlor Grid Linings you can often design a less expensive wall section thus saving critical material by taking advantage of the wearing properties and resistance to thermal shock offered by this method.

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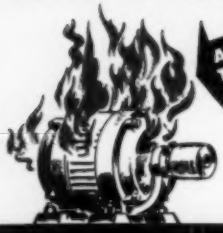

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Pictured above is the new $350,000 Hinman Research Building of the Georgia Tech, Atlanta, Ga., dedicated April 27. Doubling the area available in the main Georgia Tech Engineering Experiment Station Research Building, this structure will house a large portion of the Station's special-purpose laboratories and scientific equipment in addition to its central administrative offices.

The building, a three-story brick structure containing approximately 22,000 sq. ft. of floor space, is one of the modern, functional new buildings designed as part of Georgia Tech's expansion and renovation program. It contains chemistry laboratories which are equipped to handle the research problems of small industries. The building also contains a basic radar system, electronic laboratory, and a microbiological laboratory.

CERAMIC ENGINEERING BIBLIOGRAPHY BY E.C.P.D.

A selected bibliography on ceramic engineering listing more than 150 items under 15 classifications was recently published by the E.C.P.D. This is "Section IV" of a seven-part "Selected Bibliography of Engineering Subjects," prepared for E.C.P.D. by the Institute of Ceramic Engineers. It will serve as a guide to those who wish to continue studies in engineering and allied fields and will be a valuable addition to private libraries. These bibliographies were prepared by the E.C.P.D. Training Committee with the cooperation of teachers of technical subjects and professional engineers active in the fields covered by them. Copies of the 8-page bibliography on ceramic engineering may be obtained from E.C.P.D., 29 West 39th Street, New York 18, N. Y. Price per copy is 25 cents.

AVAILABLE WOOD IN STATE OF WASHINGTON

Approximately 210 million cubic feet of unused wood resources are available annually in the state of Washington according to Summary Report No. 1—Unused Wood Inventory, published by the Institute of Forest Products. On a statewide basis, the leftover wood as a raw material would produce 140 million gallons of industrial alcohol, "now a critical item." This publication reveals by colored maps and graphs valuable facts and figures never before available on the amount, location and accessibility of unused wood supplies in the state. The basic purpose of the inventory, it is stated, is to assist in the establishment of new wood-using industries. The inventory, requiring 18 months to complete was initiated by a directive of the state legislature in 1947 and appropriations were made in 1949 to finance the project. Copies of the report may be obtained free at 303 Anderson Hall, University of Washington, Seattle 5.

NEW GRADUATE DEGREE PROGRAM AT RALEIGH

A full-time graduate program of course work in the fields of ceramic, chemical and electrical engineering, together with a variety of supporting courses in mathematics and physics will be initiated at North Carolina State College, Raleigh, N. C., during the period June 11-Aug. 31.

The chemical engineering offerings include courses in Chemical Reaction Rates, Distillation, Seminar and Research. These are to be conducted by Russell Hazelton, associate professor of chemical engineering, a member of the North Carolina's regular staff, and a member of A.I.Ch.E.

These advanced courses are available to anyone interested and graduate credit can be obtained by those who can fulfill the requirements for admission to the Graduate School. This program will enable graduate students to obtain an M.S. degree with three summers' work.

NOW IT'S UNIVERSITY OF RHODE ISLAND

By action of the General Assembly of the State of Rhode Island and Providence Plantations the name of Rhode Island State College has been changed to University of Rhode Island. This change became effective March 23, 1951.

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for long-term exposure at

650 F. to 850 F.

take a Closer Look at

MECHANICAL PROPERTIES

In apparatus where tubing must withstand high internal pressures at elevated temperatures, *mechanical properties* of the tubing-steel are important determinants of wall-thickness and size. Evidently, any lasting improvement in the physical properties of a given steel will allow the designer a greater latitude in the selection of tubing, with possible advantages in the reduction of weight and cost. Croloys 2¼, 5, and 7 have long been popular in the fully annealed state for normal service conditions up to 1250 F. Now it is established by recent B&W tests that the *increased* mechanical strength obtained by normalizing and tempering these alloys is substantially unaffected by long-term exposure to temperatures up to 650 F.; and that Croloys 5 and 7 maintain these improved properties even at temperatures up to 850 F. Complete details of the tests are covered by Alloy Letter No. 265, available on request.

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

The Rise and Times of An Abstract Thinker

Josiah Willard Gibbs. The History of a Great Mind. Lynde P. Wheeler, Yale University Press, New Haven, Conn. (1951) 264 pp. $4.00.

Reviewed by Kenneth A. Kobe, University of Texas, Austin, Tex.

THE first Ph.D. degree in engineering to be granted in this country, which was also the second Ph.D. degree in science and the fifth Ph.D. degree granted, was received by J. Willard Gibbs from Yale University in June, 1863. Those who had paused to read the little book on "The Early Works of Willard Gibbs in Applied Mechanics" by L. P. Wheeler, E. O. Waters, and S. W. Dudley, had already been forewarned of the skeleton in the Gibbs closet that revealed that he had been listed as a student of engineering during his five years of graduate study at Yale. They had read Gibbs' Ph.D. thesis, "On the Form of the Teeth of Wheels in Spur Gearing," possibly obtained a copy of his U. S. patent 53,971 (1866) for an improved car brake, and examined the mechanism of the Gibbs governor for steam engines. To others, the engineering background of Gibbs may come as a surprise.

It is hoped that university administrators will not learn that Gibbs accepted an appointment in 1871 at Yale as professor of mathematical physics without salary and continued without salary until 1880, when Johns Hopkins University offered him a professorship at $3000 per year. The Yale administration was persuaded to offer Gibbs a salary of $2000, which held Gibbs in his life-long New Haven surroundings. During the period 1871-80 Gibbs had published his three papers on thermodynamics, including the monumental "On the Equilibrium of Heterogeneous Substances." In these days of "up-or-out" rules, administrative pressure for research, and government-sponsored group projects, how different and enviable is the serenity of Gibbs engrossed in his development of fundamental ideas in thermodynamics, mathematics, optics and statistical mechanics.

The biographer is Lynde Phelps Wheeler, who entered Yale about 1890 and received his Ph.D. in physics in 1902 for work done under Gibbs' supervision. He taught physics at Yale from 1901-1926, then was with the Naval Research Laboratory and the Federal Communications Commission. His intimate knowledge of Yale in the Nineties, the students and colleagues of Gibbs, as well as his ability to appraise and interpret the worth of Gibbs' works, and above all, his ability to express himself with clarity and feeling, have made this biography far more than the chronology of an individual. The subtitle, "The History of a Great Mind," indicates the aim of Wheeler to show the developing and maturing of a great scientific mind. The inception of the biography, as well as a tribute to the biographer, is given by E. B. Wilson [*American Scientist* **39**, 287 (April, 1951)].

The biography in its 12 chapters presents the background of the Gibbs family; Willard Gibbs' early education; his graduate and tutorial work at Yale, followed by travel and study abroad for three years; his appointment at Yale; his work in thermodynamics and its recognition abroad; his work in mathematics and optics, with widening contacts in scientific fields; his last work in statistical mechanics; a tribute to Gibbs as a teacher; and his last years. Included in the appendix is the first paper presented by Gibbs to the Connecticut Academy in 1866 on units and dimensions for interconversion of mass and force units in which Gibbs proposed a new unit of length.

One cannot resist the stimulation imparted by the intellectual creating of Gibbs, and all join in Wheeler's tribute: "Like Sir Isaac Newton's *Principia*, this work [Equilibrium of Heterogeneous Substances] of Willard Gibbs stands out in the history of man's intellectual progress as an imperishable monument to the power of abstract thought and logical reasoning."

Chemical Who's Who. Edited by William Haynes and Winfield Scott Downs. Lewis Historical Publishing Co., Inc., New York, N. Y. (1951) 1896 pp. $15.0..

THIS third edition of one of the "Who's Who" series, is a biography in dictionary form of the leaders in chemical branches of industry, research, and education. The scope of the book has been broadened now to include all chemical leaders, not only the chief executives of chemical companies and their department heads and branch men but the superintendents of plants, purchasing agents, librarians and directors of research; as well as chemical brokers and dealers, importers and exporters, and as an important addition, leaders in the field of chemical education. This edition actually contains 50 per cent more biographies than the second edition. William Haynes, the former publisher and now one of the editors, explains in the introduction his retirement from active publishing and his reasons for turning over the work to the Lewis company, publisher also of "Who's Who in Engineering" and "Who's Who in New York." It is promised that this compilation and dictionary will hereafter appear regularly at three or four-year intervals.

The Practical Engineer Pocket Book. With technical dictionaries in German, French and Spanish. Edited by N. P. W. Moore. Pitman Publishing Corp., New York (1951) 744 pp. $3.00.

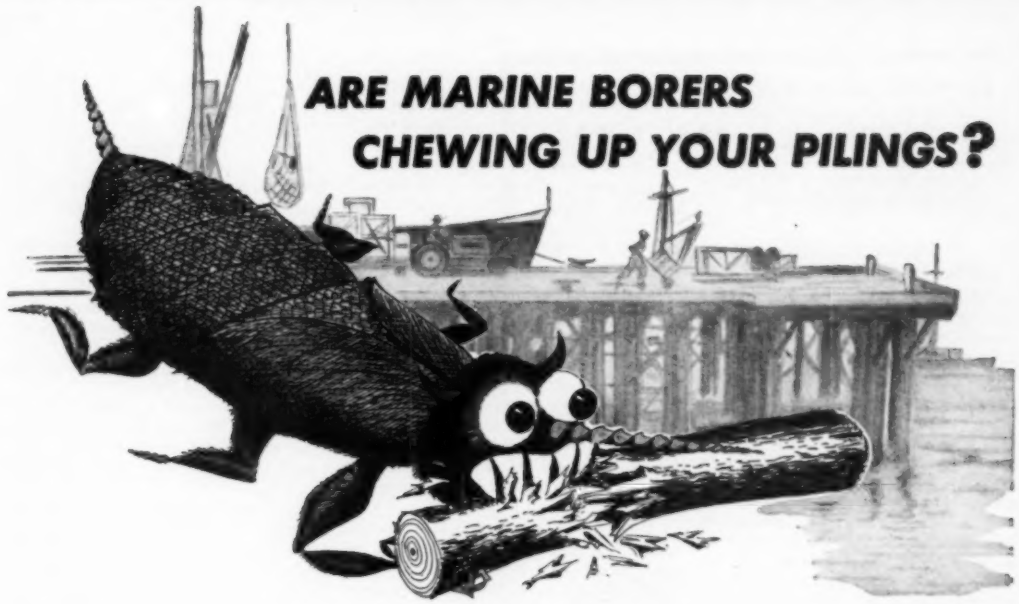
THE book listed above, primarily a British publication, is in its 63rd year of issue. It contains technical dictionaries in German, French and Spanish and one of the unique features of the handbook is its form, that of a top-bound pad, 3¾ in. wide, and 6 in. long.

This pocketbook contains the usual technical tables such as units of weights and measures, areas, logarithmic tables, sines, and some physical constants. Essentially it is a mechanical engineer's book and features many items which would be of use mostly to this calling. For the British engineer this should be a handy pocket companion. However, for American engineers its value would be limited by the fact that some of the tables are primarily British standards, but much in the book has been presented in such a way that an American engineer would not have too much difficulty in finding his way about.

The English and French and Spanish dictionaries are valuable additions and give a comprehensive list of technical words.

Book Received

Production Forecasting, Planning, and Control. E. H. MacNiece. John Wiley & Sons, Inc., New York, N. Y. 305 pp. $5.50.



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Other advantages of steel pilings are: more strength ... better fire resistance ... less maintenance ... lower insurance rates.

"National" graphite ground anodes also provide the most practical and economical cathodic protection for *buried pipe lines, tank farms, oil well casings, water mains, underground cables, ship hulls* and dozens of other products buried in earth or submerged in water.

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DU PONT DEDICATION

(*Continued from page 24*)

ization of about 1500, added to which there are also about 1000 technically trained people working in the laboratories of the company at other locations."

Station Inspection

Six of the 19 new buildings were included in the inspection. At the engineering research laboratory visitors were shown what happens when metals are attacked by corrosive liquids. This was done via a motion picture taken through a microscope at a frame a minute, and speeded up for projection.

Equipment of the laboratory was shown and outstanding was the high-pressure laboratory with a hydraulic system which will produce pressures as high as 200,000 lb./sq.in. Essentially, this experimental work is designed for learning more about construction materials so that plants operating at lower pressures can be built and operated most economically and safely.

Other new research projects shown visitors during the day, consisted of the first public exhibition of a new experimental cloth made from Du Pont's Orlon acrylic fiber, which was specially processed so it would not burn at temperatures of as high as 1400° F. New synthetic furs were shown, and the new polyester fiber Dacron was exhibited in the form of suits and slacks which had retained their resilience and shape after being worn, dry-cleaned, and washed.

Other advances in the field of textiles are fire hose manufactured with Dacron polyester which makes it possible to put 40% more hose on a fire truck without increasing its load, new air mail bags which are 3 lb. lighter than those generally in use, and which would save $1.95 on every bag of mail flown from New York to San Francisco.

Part of the exhibition of the polychemicals department concerned the polymerization of acrylic resin monomer (Lucite) by ultra-violet rays. By the use of patterns interposed between the source of the light and unpolymerized plastic, patterns can be made to form. The acrylic monomer is first mixed with a dye, pearl essence, and a catalyst, and poured into a cell formed by two glass plates separated by a gasket. This follows the conventional method of making cast sheets, but the ultra-violet, and catalyst stimulate polymerization, and the mark suggests and develops the pattern. The growth of polymer chains lag in those portions of the plastic not exposed to the light, and the shrinking which accompanies the transition of the liquid monomer into a solid, takes place less rapidly in the shaded or masked areas of the cell. This sets up flow currents in the thickening plastic, which in turn causes the flat particles of pearl essence to orient and develop a pattern.

The Grasselli Chemicals department demonstrated colloidal silica and showed how, when mixed with oil, it will form a heavy grease which will not only retain its consistency at temperatures that melt soap thickened greases, but laboratory tests show it will stand up well in lubrication uses. The colloidal silica was also shown as a 30% solution in water, for making water-emulsion floor waxes which have superior slip resistance, without sacrifice of gloss.

Various insecticides were displayed and demnostrated. Phosphorus containing compounds (ethyl para-nitrophenyl thionobenzenephosphate) were held to have great promise in the insecticide field.

Exhibits of titanium metal and a flame-retardant for textiles were part of the program of the pigments department which also revealed that isobutyl titanate may be important as an intermediate for the formation of a heat-resistant paint. The titanate hydrolyzes in contact with air, and the by-product alcohol evaporates, leaving an adherent, nonflammable film of titanium dioxide.

Two other buildings of importance were visited during the day. One was the chemical department, a separate organization devoted to research but serving the entire company. Its major activity is to conduct fundamental research, which, according to the department spokesman, was defined as "original exploration for the advancement of scientific knowledge without regard to a specific commercial objective." It was in this building that the fundamental laboratory unit, which Du Pont developed as a result of intensive study in laboratory efficiency, was shown. Basically the laboratories are two-man rooms with each chemist occupying one half of the room, having his own fume hood, work benches, and desk.

The second building of importance was the Lavoisier Library which houses about 25,000 volumes. It was named out of tribute to Lavoisier who was an outstanding scientist, chemist, and mentor of Eluthère Irénée Du Pont, the founder of the company. Du Pont was forced to flee to this country during the French Revolution which saw Lavoisier die on the guillotine.

In addition to the microfilming and special services that the library boasts of, there is a complete translating service as well as individual offices which may be occupied by research chemists and engineers over any length of time they wish when they are conducting special laboratory research.

In the dedicatory speeches both Dr. Conant and Mr. Greenewalt struck the same theme—that research and science must be free in order to accumulate new knowledge.

President Greenewalt said, "it was 'essential' to recognize that the vast social and material gains America has made in the last five decades 'have not been accomplished by legislation, . . . but simply through the application and encouragement of invention and development.'"

Women were not freed from their Eighteenth Century servitude by feminist agitation, Mr. Greenewalt said, but by the invention of the sewing machine, the dish-washer, and other labor-saving home appliances, together with the revolutionary developments for handling and distributing foodstuffs.

He then observed that, if the nation is to continue to progress through the application, by industrial research, of the new principles of science, the reservoir of basic scientific information must be constantly enlarged. He continued:

"We have been fortunate in the past in having available to us the results of basic science all over the world, and I think it is fair to say that the contributions to fundamental knowledge made in the universities abroad have until now been greater than our own," he said. "This has permitted us to indulge our industrial genius, possibly without contributing our fair share to the

This new building, one of 19 recently erected is the Engineering Research Laboratory of Du Pont's engineering department. Half of the staff of 175 are technically trained engineers.

world's storehouse of basic knowledge."

Calling attention to the fact that America may no longer rely upon basic research from foreign universities, even if it wished to do so, Mr. Greenewalt declared:

In that measure it becomes essential that we make this country as self-sufficient in pure science as it has become in industrial research. . . . .

The risks of industrial research are indeed great. It takes courage, patience, and much money even to attempt it on any substantial scale. With all the many skills at our disposal, with all the fine equipment you have seen today, with men of the highest scientific attainments, with able and experienced management, a given research program has about one chance in twenty of being a commercial success.

An abundant flow of basic scientific knowledge is essential if the odds in the game we play are to be good enough for us to stay on the winning side.

Dr. Conant at one time in his address said that Soviet technology "will almost stop" once the borrowed momentum of the science of the free world has been exhausted.

Dr. Conant also stated that, "What modern science needs to maintain progress, are Twentieth Century counterparts of the great science trail blazers of the Eighteenth Century—men like Priestly, Cavendish, and Lavoisier —who could 'investigate what they pleased' and 'were free as the wind because they had no program except the everchanging one in their own hands.'"

"Similarly, advancement in applied science calls for men who, like Watt, may be guided entirely by their own ideas and, like an old-time prospector, may play a 'lone-hand.'" Dr. Conant pointed out that the "mechanical ingenuity and scientific insight" of James Watt might have proved of "no avail," had he not "been fortunate enough to join forces with a man of exceptional business skill, Matthew Boulton." He continued:

Contrast such research men with the investigator today in a university or a research laboratory who is tied to a program, perhaps, of his own making. In part because of the vast capital investment in the equipment, in part because of the source of funds, he is morally bound to carry through a project.

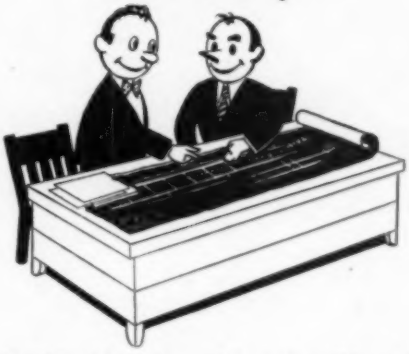
While it goes without saying that today's industrial executive, in a given area, must organize a vast amount of programmatic research, he must somehow continue to produce the equivalent of the lone inventor; he must have some individuals in his outfit who will be almost fancy free.

"I don't propose to tell him how to do it," he said. "There may well be more than one successful method. I do venture to say, however, that society would be well advised to see to it that the technological situation is so loose-jointed that the skills of different groups, in playing the role of inventor, may be pitted against each other."

(*More News on page* 40)

TIPS ON SOLVING DRYING PROBLEMS

JUST HOW DOES CONSULTING PROCTOR ENGINEERS EARLY PAY OFF?



Taking Proctor engineers into your confidence just as soon as you know that drying is to be a part of your processing line usually pays off in substantial savings—for you! It makes such plain common sense when you stop to think about it. When drying is a part of a process it is usually a vital link. As such, the equipment should be considered at the very outset of your planning. Its design is dependent upon a number of factors . . . the capacity desired and physical characteristics of the product being two of the chief considerations. Proctor engineers may recommend that to obtain a desired capacity, the product be delivered to the dryer in a certain state and this may govern the type of preliminary equipment needed. Then too, characteristics of the dried material may affect the type of subsequent equipment you will need. That is why it is advisable to consider the problem—as a whole and early! You save time, effort and money by consulting Proctor engineers early. Write today for Bulletin 361 for the complete story of the Proctor approach to solving drying problems. For a lucid explanation of Proctor Drying Systems for the Process Industries, ask for Bulletin 342 as well.

A FEW TYPICAL MATERIALS BEING DRIED IN PROCTOR CONTINUOUS CONVEYOR SYSTEMS

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Titanium Dioxide
Sulfa Drugs
Calcium carbonate
Magnesium carbonate
Clay
White Lead
Finished Lithopone
Soy Bean Protein
Lead Arsenate
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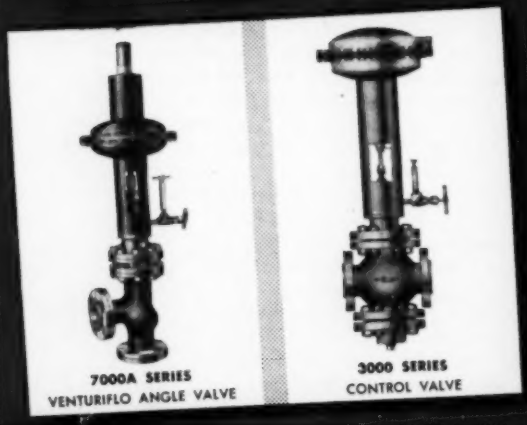

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1 • SURFACE ACTIVE AGENTS. Properties, grades, applications of Rohm & Haas surface active agents are shown in a 48-page technical booklet. Has sections on the preparation of emulsions, ten tables of data on surface and interfacial tension values, wetting time, spreading coefficients, etc. Bulletin contains examples of applications of surface active agents.

2 • CALCIUM SILICATE. Essentially a booklet for the user of building and insulating materials, Owens-Illinois Glass Co. booklet on hydrous calcium silicate building materials. Physical details of board, structural density, strength, as well as the heat insulation.

3 • SULFUR SHORTAGE. A memorandum from Freeport Sulphur Co. on the sulfur shortage. Covers the extent of the shortages, reasons, outlook for the future, sources, and uses of sulfur. An authoritative quick résumé of the complete sulfur picture.

4 • PLASTICIZER AND RESIN. General Mills reports the manufacture of resinous alcohol-8, a mixture of mono-, di- and tri-glycerides of rosin and fatty acids. Combines properties of plasticizer and a resin. Effectively plasticizes nitrocellulose lacquer films, improves adhesive qualities, makes them water-resistant, alcohol-resistant, etc. Soluble in lacquer solvents, nonvolatile, nonmigratory. Drum quantities available for evaluation and commercial use.

5 • MoS_2 AS A LUBRICANT. A collection by Climax Molybdenum Co. of technical papers on the use of molybdenum disulfide as a lubricant and antifretting agent. Many of the articles appeared in English journals, in N.A.C.A. publications, etc.

6 • THIOVANIC ACID. Vacuum distilled thioglycolic acid is covered in a technical data bulletin by Evans Chemetics, Inc. Outlines properties, specifications, reactions, suggested uses, etc.

7 • LINDANE AND DDT. A service bulletin on the use of lindane and DDT in commercial pest control, by Pennsylvania Salt Mfg. Co. Sections on mixing other products for pest-control.

8 • FLATTING AGENT. Use of Santocel C, a microscopically divided silica aerogel as a flattening agent in varnishes, lacquers, baking enamels and flexible vinyl coatings is explained in detail in a bulletin from the Monsanto Chemical Co. Covers most of the technical data necessary such as oil absorption, weather resistance, typical grinding and reducing procedures, and properties of material.

9 • RESIN ENAMEL. U. S. Stoneware Co. has developed a new enamel finish paint for use where weatherability, quick drying time and better than average resistance to chemical corrosives is required in a paint for wood, metal, and concrete.

10 • STANNATES. Production of barium, calcium, magnesium, lead and bismuth stannate is announced by Metal & Thermit Corp. Now being made in pilot plant quantities. Technical data assembled by company on possibilities of stannates as ingredients of ceramic capacitor bodies, dielectric and piezoelectric

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bodies, special glasses and color stains.

BULLETINS

15 • GLASSWARE AND EQUIPMENT. From adaptors to vacuum gauges in 210 pages, an indication of the coverage of glass equipment illustrated in a new bulletin by the Ace Glass, Inc. Every conceivable type of apparatus plus a special section on microchemical equipment and other pieces of apparatus.

16 • DYNEL. A new staple fiber, a vinyl chloride-acrylonitrile polymer made by Carbide & Carbon Chemicals Co. is described in an 8-page pamphlet. Properties of the material are given, its resistance to various chemicals, combustion, mildew, etc., are shown.

17 • CAST STEEL VALVE. Gate valves of cast carbon steel from ½ to 2 in. are described in a new bulletin of Pacific Valves, Inc. Three types are offered—bolted bonnet, union bonnet, and union bonnet with an inside screw. Material specifications, prices, dimensions, test pressures, etc., are all shown.

18 • PIPING POINTERS. A manual for training beginners and refreshing veterans in industrial piping work, which covers fundamentals of sound piping practice, is offered by Crane Co. A 16-mm. sound film is also available on the same subject which is ideal for training men in piping techniques. In simple, nontechnical language shows basic valve designs, names parts, tells principle function of valves. Manual also includes a valve selection guide.

19 • MUFFLERS. For 2- and 4-cycle internal combustion engines, stationary type, The Fluor Corp., Ltd., has designed a muffler system applicable to a wide range of makes, models and hp. ratings. For the petroleum, gas, gasoline and gas transmission industries, etc., where such prime movers are used and where a silent operation is desirable. Mufflering system explained and shown via detailed drawings. Two series are offered, single elements in a muffler, and dual element muffler. Used for engines in 150 to 2400 hp. class.

20 • 1.5 METER SPECTROGRAPH. Applied Research Laboratories describe a new 1½-meter grating spectrograph to satisfy the demand for a small, flexible instrument. Bulletin gives information on camera, castings, control assemblies, magnetic shutter construction, other specifications and suggested laboratory arrangement for the instrument.

21 • CORROSION CONTROL. Corrosion control coatings based on synthetic rubber for protection of machinery and masonry against acids, alkalis, salts, caustics, etc., from Casey & Case Coating Co. Tells of surface preparation, application, advantages, describes machinery enamels, floor coatings, etc.

22 • COOLING TOWER. A J. F. Pritchard & Co. cooling tower in which the design has been aimed at better drift retriever louvers, better primary water distribution, and maximum use of bronze and redwood to induce longer life. Sectional folder shows features plus pictures of distribution systems, pressure nozzles, slide valves, side and exterior views, framework, etc.

23 • PROCESS EQUIPMENT. Equipment for the chemical process industries made by Artisan Metal Products, Inc., is well illustrated and described. Covers tanks, evaporators, condensers, heat exchangers, piping, stills, reactors, kettles, pilot plant equipment and autoclaves, service of the company, engineering department, etc.

24 • VACUUM SLIDE RULE. A slide rule from the F. J. Stokes Machine Co. designed for quick calculations in vacuum research and processing work. The slide rule determines pump capacity to evacuate a given volume to a specified vacuum in a given time, and time required to reach a specified vacuum in a given volume with a pump whose capacity is known. Will also determine vapor pressures of water at various temperatures, capacities of round tanks; conversion tables are included as well as boiling points of various solvents.

25 • CRUSHERS. Horizontal saw-tooth crushers and vertical cone-type crushers of from 3 to 30 hp. in the saw-tooth crusher and 4 to 9 hp. in the horizontal cone crusher are described in a new catalog of the Mercer-Robinson Co., Inc. Descriptions and illustrations of each machine as well as details of grinding parts, construction, etc.

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26 • *SAFETY HEADS.* A primer on safety heads which begins at the very definition of a safety head and carries the engineer on through to where safety heads should be used, how to choose assemblies, and all other information pertinent to the use of this safety feature. From Black, Sivalls & Bryson, Inc. Charts and tables cover specifications, sizes, pressure ratings, materials from which safety disks are made, etc.

27 • *GASKETS.* Specifications, descriptions, properties, uses and other details of all gaskets made by United States Gasket Co. Covers spiral wound, corrugated metal, heat exchanger, cylinder head, ball-joint, serrated gaskets, woven gaskets, Teflon, plus tables of data and conversion. Forty-eight pages of data make this book exhaustive.

28 • *PRE-FABRICATED PIPING.* Illustrated booklet which discusses advances made in the field of high- and low-pressure piping subassemblies describes and pictures pipe bends, coils, headers, manifolds, welded assemblies for the petroleum, chemical, steel, pipe-line transmission, etc., industries. Bulletin by Western Piping Supply division of the Lummus Co.

29 • *STAINLESS HANDBOOK.* A complete handbook of 104 pages on the properties and methods of working seamless and welded tubes and pipe of stainless steel is intended for engineers by the Babcock & Wilcox Tube Co. Leather bound, 8 x 5 in., a handy size for desk or pocket, deals with methods of manufacture and inspection, corrosion and oxidation resistance and methods of working and fabrication of the B & W stainless Croloy tubing steels. Technical data for eight different types covering physical and mechanical properties, processing data, list of applications, tables of physical data, section on fabrication of tubes into heat exchangers, etc.

30 • *SUBMERGED COMBUSTION.* Description of submerged combustion, a self-contained unit for heating and evaporating liquids, which uses any natural or manufactured gas for fuel and is fired below the surface of the liquid. Adapted to almost any kind of a solution—acid, salt, etc., and offered by the Submerged Combustion Co. of America, Inc. Bulletin covers efficiency, schematic diagrams, installation, thermal efficiency, control, etc.

EQUIPMENT

40 • *QUICK COUPLINGS.* For use in pipe lines carrying oil and gasoline, water, air, etc., a quick coupling made by Mead Cornell & Co. Opens and closes by hand in less than a quarter turn, self-positioning, locking seat.

41 • *NEW VACUUM SYSTEM.* RCA engineering products department design a new vacuum system for use in research, control, and production. For evaporation of metals and salts, sputtering, applying metallic films, vacuum distillation, drying, preparation of specimens, physical studies, etc. Uses mechanical fore pump and oil diffusion pump to 0.1 μ Hg. in less than 7 min. Cathode discharge gauge to measure vacuum.

42 • *GAS-HEATED MIXER.* Where mixing chemicals, dyes, foods, etc. and heat control of a very sensitive nature is desired, L. O. Koven & Brother, Inc., offered a new gas-fired mixer 36 in. in diameter. Works under 5 lbs./sq.in. pressure with gas burners rated at 300 cu.ft./min.

43 • *OSCILLATING CONVEYOR.* Link-Belt Co. with a new conveyor of oscillating trough type for loose bulk materials at moderate capacities. For handling foodstuffs, chemicals and other materials where cleanliness, contamination or corrosion is a factor. One-piece metal trough with high sides, supported on a one-piece flexible member which functions as spring in absorbing the energy of the trough movement. Widths of 8 to 24 in., various materials, motion given by constant stroke eccentric.

44 • *DRAWING PAPER.* Kodagraph Autopositive Paper, a translucent, durable drawing reproduction paper is now being distributed by Eastman Kodak Co. for the drawing copy field. The new paper is coated with an emulsion and handled on ordinary reproduction equipment. Blueprints and direct process prints can be turned out 30% faster.

45 • *SCINTILLATION SCALER.* A scintillation scaler which may also be used for Geiger and proportional counting is a new product of Nuclear

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Research and Development, Inc. Has a fast linear amplifier, an electronic discriminator, and a well-regulated high voltage supply.

46 • MINIATURE STEAM GENERATORS. An automatic generator available in four sizes beginning at a water capacity of 2 gals. is a new product of the Palo Laboratory Supplies, Inc. Automatic pressure regulator delivers up to 30 lbs. working pressure steam generated at 100 lbs./sq.in.

47 • PUMP LINER. Liners for pumps of the Vanton Pump Corp., made of polyethylene and vinyl resins and able to withstand corrosive action of sulfuric, hydrochloric, and other chemicals. Pump action depends upon an eccentric rotor squeezing the liner and pushing the liquids before it. Now available in capacities ranging from fractional to 5 gals./min. Application is bottle-filling, blood-pumping, gas-sampling, etc. Has no stuffing boxes, packing glands, seals, etc.

48 • OZONATOR. A new model laboratory ozonator by The Welsbach Corp. for producing laboratory quantities of ozone. Intended for testing potential value of ozone as an oxidizing agent in various chemical processes, phenol and cyanide destruction in industrial wastes, and reduction of tastes, colors, and odors in water purification.

49 • TUBE CLEANER. For cleaning heat-exchanger tubes in process and refinery installations, Thomas C. Wilson, Inc., offers a new model. Air-driven, rotary-shaft, drill-type, scavenges the tubes with air or water while cleaning. Operates on 50 lb. pressure air, and works on 3/8 in. up to 3 in. O.D. tubes.

50 • LINE LOCATOR. For tracing underground pipes, locating valves, manholes, etc. Wilkinson Products Co. offers a line locator combining a transmitter and receiver. Same principle as mine detectors. Has improved features which enable it to be operated without interference from broadcasting stations, etc.

51 • MIXERS. A line of mixers including an explosion-proof mixer for paint and lacquer—products of the Standard Electric Mfg. Co. Available in sizes of 1/4 to 1 hp., portable type with adjustable clamp and base, propellers from 4 to 7 in., and rev./min. from 1140 to 1725.

52 • DIRECT FLOW PUMP. A 3-in. stroke triplex, direct flow pump has been added to the over-all line of the Aldrich Pump Co. Operates at speeds up to 500 r.p.m., power ranges up to 50 hp., pressures to 3800 lbs./sq.in., will deliver 96 gal./min. at 790 lbs./sq.in. at 500 rev./min. Plunger sizes can be changed to meet alterations in pressures or capacities.

53 • CENTRIFUGAL PUMP. The Bell & Gossett Co.'s new, small centrifugal pump of 316 stainless steel, 3/4 to 1 1/2 in. discharge, hp. from 1/4 to 2, teflon seals, easily demounted for servicing and cleaning.

54 • HEATERS. For heating air, special atmospheres, gases, or liquids without contamination with combustion products up to 1600° F. Brown Fintube Co. offers new stainless steel outer shell, Inconel center tube with integrally welded extended surface nickel fin heater. Use either oil or gas, quick-starting and slated for use in processing industries, for drying chemicals, dehydrating foods, annealing glass, etc.

55 • GROUND ANODES. For the cathodic protection of pipe lines, tank farms, refinery equipment, substations, underwater metal structures, National Carbon Co. has new-sized graphite ground anodes. Complete details on the new anode as well as engineering information on the use of ground anodes for cathodic protection available.

56 • HOLO-FLITE. Western Precipitation Corp. with a new heat exchanger (primarily for cooling) which features hollow screw-type impellers through which heat-transfer agents flow. Heat is transferred from material on outside of the hollow screws. Processed materials pushed forward toward the cooler end by the rotation of the hollow screws. In the standard equipment two such hollow-flight screws are arranged side by side in a common housing. Process material flow rate can be controlled and unit, in addition to cooling can be used for cooking, desolventizing, etc. Heat-transfer agents such as water, steam, hot oil. Screws are in four diameters 7 in. to 16 in. with flight lengths of 8 ft. to 20 ft. Rotating speed 1-12 rev./min. Used for cooling chemicals, sand, cement, solvents, foods, etc.

57 • AIR VALVES. For removal of contaminants and precipitates from compressed air lines, aftercoolers, sumps, tanks, a newly engineered line of valves which automatically remove such foreign matter, by the Wilkerson Corp. When valve is passing air or gas, precipitates are dropped into the valve chamber, while in "off" position, sump bottom is opened and contamination blasted out.

58 • DYNEL FILTER CLOTHS. Dynel an acrylic staple fiber is now being used in commercial filter cloths according to Carbide & Carbon Corp. Used in various installations, Dynel has resisted 30% caustic solutions in temperatures of from 70 to 200° F. for ten months and is still in use. Used to filter hot acids, ferric chloride solutions, and other corrosive materials.

59 • COMBINATION VALVE. A valve that combines the advantages of an actuated control valve and a handwheel valve is new with the Annin Valve Co. Uses an Annin domotor operator as a control valve with a handwheel valve mounted on the underside of the single-seated valve body. When automatic control is desired the handwheel valve is opened fully but during startups or instrument repair period the handwheel provides positive manual control without changing valves. Pressures up to 3000 lbs./sq.in. and temperatures up to 1000° F.

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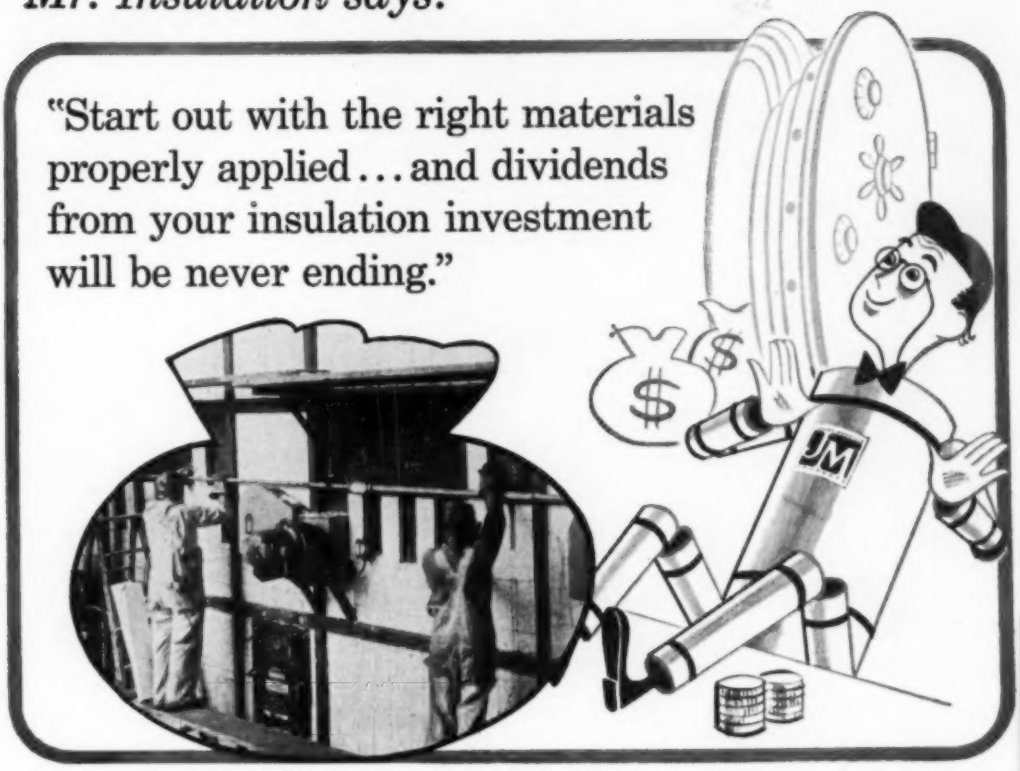


Here are two important reasons why it will pay you to let Johns-Manville serve as your insulation headquarters:

YOU GET THE RIGHT MATERIALS — Regardless of the service conditions on your job, Johns-Manville has an insulation that fits the need. That's because Johns-Manville manufactures a wide variety of insulations of asbestos and other selected raw materials—for service from 400F below zero to 3000F above. Johns-Manville offers this complete line because industry requires many types of insulations and because no one material can properly serve as a jack-of-all trades for use on all jobs.

YOU GET THE RIGHT APPLICATION— Insulations serve at top efficiency only when properly applied. J-M Insulation Contract Firms have men with generations of insulation experience and training in Johns-Manville application methods. The way they engineer your job is your assurance that your insulation investment will pay a high return through the years.

Why not call on insulation headquarters for engineering advice about your insulation work. J-M Insulation Engineers are available to help select the *right* insulation for your particular service conditions. Write Johns-Manville, Box 290, New York 16, N.Y.

Johns-Manville *first in* **INSULATIONS**

Spencer Chemical Co., Kansas City, Mo., recently put into operation the world's largest ammonium nitrate prilling plant. Though only one of the two 185-ft. towers shown above has been put into production, the second tower is expected to be completed by August. The anticipated capacity after that date is for more than 1,000 tons of prilled material per day.

The new plant has been built as a part of Spencer's Jayhawk Works near Pittsburg, Kan. Jayhawk now produces ammonia and fertilizer ammoniating solutions and the addition of fertilizer grade ammonium nitrate to the production schedule makes this plant a completely integrated operation.

The new Spencer plant is based on the prilling processes originated in Canada, but the design was developed by Spencer's own engineering department and embodies a number of unique features. Construction was carried out by a Spencer subsidiary, Quaker Valley Constructors, Inc, and was completed in approximately twelve months.

Members of the A.I.Ch.E. paid a visit to the Jayhawk plant during the Kansas City meeting last month, and inspected the complete operation which begins with natural gas and processes it to ammonia, nitric acid, dry ice, and ammonium nitrate.

STUDENT CLASSIFICATION ENDORSED BY COMMITTEES

Twenty-four of the Nation's educational, scientific and industrial leaders, who have studied for more than two years problems of trained manpower in relation to military and civilian needs, have unanimously endorsed the recently announced regulations on classification of college students by local boards. Stephen L. Tyler, Secretary, American Institute of Chemical Engineers, is chairman of the Engineering Sciences Committee which includes in its membership G. W. Bailey, executive secretary, The Institute of Radio Engineers; S. C. Hollister, dean, The Engineering College, Cornell, and Alex C. Montieth, vice-president, Westinghouse Electric Corp.

Mr. Tyler was among those who noted that none of the new provisions creates any exemption from military service and none takes from the local board the classification powers and responsibilities fixed upon them by the Congress in the 1948 Selective Service Act.

The advisory committees to the Director of Selective Service, reviewed their policy recommendations made public in a report to General Hershey, Dec. 18, 1950, and also considered objections which have been raised since the program was announced in the Executive Order of March 31, 1951.

The committee pointed out that the engineering sciences, the physical sciences, the biological sciences, the social sciences, the humanities, and the healing arts all made significant and essential contributions to the last war and will continue to be vital to the national defense as well as the national welfare. The committee stressed the fact that the program does not provide for an escape from military service but makes provision for the deferment of military service of those found to be best qualified to continue their studies in the national interest.

FOUR REACTOR STUDIES MAXIMUM BY A.E.C.

The Atomic Energy Commission announced negotiations are nearing completion with four groups of business and industrial firms under a previously announced program for expanded participation in reactor development projects and that no additional groups can be admitted at this time.

The four proposals provide for special studies of the practicability of business and industry building and operating reactors for the production of fissionable materials and power. They were submitted by:

Monsanto Chemical Co., St. Louis, and its associate, Union Electric Company of Missouri, St. Louis.

Detroit Edison Co., Detroit, and the Dow Chemical Co., Midland, Mich.

Commonwealth Edison Co. and the Public Service Company of Northern Illinois, Chicago.

Pacific Gas and Electric Co. and the Bechtel Corp., San Francisco.

The two laboratories principally concerned are the Argonne National Laboratory at Chicago and the Oak Ridge National Laboratory at Oak Ridge, Tenn.

Engineering Manpower—What You Can Do About It

EJC Engineering Manpower Commission Suggests:

I IF YOU are a graduate engineer or have had three years of responsible charge of engineering work, and are in the Armed Forces assigned to non-engineering work, take the following steps:

1 Request through your chain of command: (*a*) Assignment to Corps of Engineers; (*b*) classification as special professional personnel; and (*c*) attachment to nearest technical detachment.

2 If you receive no satisfaction, write to EJC Engineering Manpower Commission, 29 West 39th Street, New York 18, N. Y., and provide the following information: (*a*) Record of education; (*b*) record of industrial experience; (*c*) details of present non-engineering assignment; (*d*) date of induction; date of request for engineering assignment; and replies received, if any. (EJC will send these facts to persons in a position to take up your case on an individual basis.)

II IF YOU are an engineer of draft age employed in industry.

1 Notify your employer of your status.

2 Write for a copy of Bulletin No. 1 on deferment procedures and place this in employer's hands.

3 If employer's efforts fail and you are inducted, immediately request through your chain of command: (*a*) Assignment to Corps of Engineers; (*b*) classification as special professional personnel; and (*c*) attachment to nearest technical detachment.

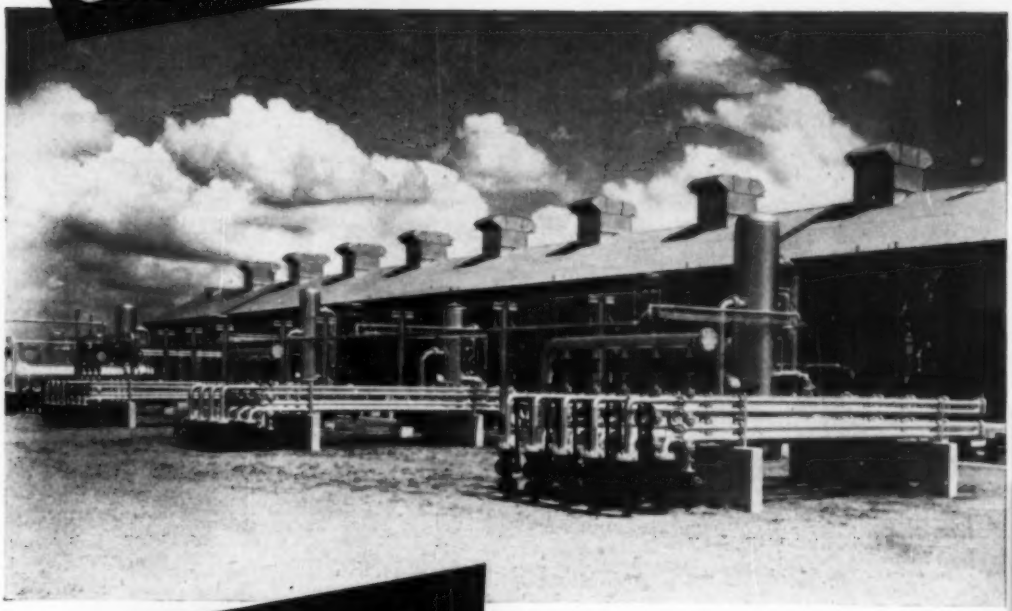
III IF YOU are an engineering student:

1 Remember you have a 30-day postponement of induction after graduation to get a job in the defense industries.

2 Once employed, follow suggestions listed under II.

(*More News on page* 44)

Reduce Obsolescence in your plant



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● Brown Fintube's interchangeability of parts, exacting design and precision manufacture has "licked" obsolescence.

The sections can be used in one bank after another — on different duties — and different products. A bank can even be broken up and the sections shipped to two or more plants, miles apart, re-assembled and reused. Sections not in use serve as "stores" for other sections on stream. They are never obsoleted by changes in duty or plant re-arrangements. You can use and reuse them until they are completely worn out. Estimates and quotations furnished promptly. ***Write for Bulletin No. 481.***

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CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E. which states:

Election to membership shall be by vote of the Council upon recommendation of the Committee on Admissions. The names of all applicants who have been approved as candidates by the Committee on Admissions, other than those of applicants for Student membership, shall be listed in an official publication of the Institute. If no objection is received in writing by the Secretary within thirty days after the mailing date of the publication, they may be declared elected by vote of Council. If an objection to the election of any candidate is received by the Secretary within the period specified, said objection shall be referred to the Committee on Admissions, which shall investigate the cause for such objection, holding all communications in confidence, and make recommendations to the Council regarding the candidate.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before *July 15, 1951*, at the Office of the Secretary, American Institute of Chemical Engineers, 120 East 41st St., New York 17, N. Y.

APPLICANTS FOR ACTIVE MEMBERSHIP

Thomas W. Baker, *Linden, N. J.*
George L. Barnes, Jr., *Louisville, Ky.*
James E. Barry, *Niagara Falls, N. Y.*
C. D. Bell, *Wilmington, Del.*
William J. Borns, *Paulsboro, N. J.*
Joseph George Brown, *Stoughton, Mass.*
William M. Campbell, *Chalk River, Ont.*
E. M. Carter, *Madison, Tenn.*
Richard F. Cole, *Pensacola, Fla.*
George B. Crane, *Drexel Hill, Pa.*
Henry W. Dahlberg, Jr., *Chicago, Ill.*
Lloyd E. Dean, *Phillips, Tex.*
W. J. Degnen, *New York, N. Y.*
J. E. Dlouhy, *Forest Park, Ill.*
Roy E. Dunn, *Wilson Dam, Ala.*
Nelson J. Ehlers, *New Martinsville, W. Va.*
John C. Fedoruk, *Baton Rouge, La.*
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B. L. Harris, *Baltimore, Md.*
Bertram J. Holsgrove, *Quebec, P.Q.*
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F. W. Morgan, *Beacon, N. Y.*
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David H. Roberts, *White Plains, N. Y.*
Albert B. Root, III, *Louisville, Ky.*
J. Paul Sharp, *Kirkwood, Mo.*
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C. P. Nunley, *Cleveland, Ohio*
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Howard Isermann, *Belleville, N. J.*
John G. Ishikawa, *Rochester, N. Y.*
Maurice E. Kalen, *Richmond, Va.*
F. M. Kennedy, *Monaca, Pa.*
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Norman B. King, *Squantum, Mass.*
Frank E. Klapheke, *Louisville, Ky.*
James Kordig, Jr., *Chicago, Ill.*
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Thomas A. Leeper, *Baton Rouge, La.*
William R. Lehrian, *Pittsburgh, Pa.*
Arthur F. Limper, *Baton Rouge, La.*
J. Lizarralde, *Cali, Columbia, S. A.*
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Donald Ost McCarthy, *Bartlesville, Okla.*
William E. McWhirter, Jr., *New Orleans, La.*
Raymond E. Mietz, *New York, N. Y.*
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James A. Sample, *Somerville, N. J.*
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Roger L. Sullivan, *Buffalo, N. Y.*
Edward Francis Szymanski, *Harrison, N. J.*
M. S. Teat, *Cactus, Tex.*
Robert N. Tennyson, *Akron, Ohio*
Charles Earl Villars, *Lincoln, Neb.*
George W. Walpert, *Boulder, Col.*
R. A. Walther, *So. Charleston, W. Va.*
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Edwin N. Woistmann, *Buffalo, N. Y.*

SECRETARY'S REPORT

S. L. TYLER

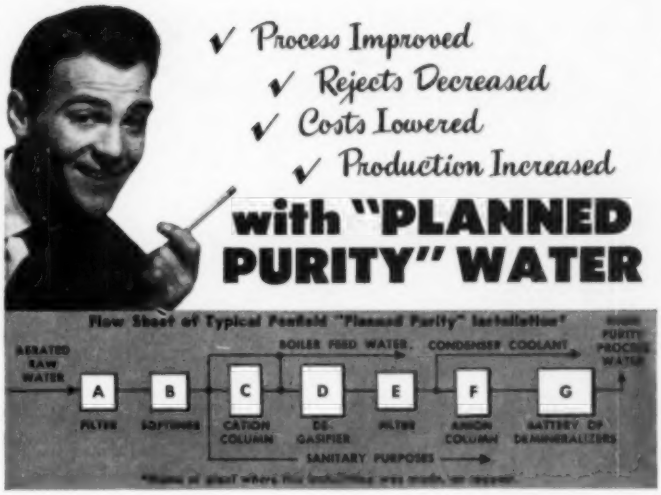
THE Executive Committee of the Institute met May 3 at The Chemists' Club, New York, and approved the election of those whose names appeared in Chemical Engineering Progress of April, 1951. There were also 82 elections to Student membership bringing the total of Student members to 2,719. The following were appointed as members of the Local Sections Committee: R. W. Krebs (Baton Rouge), G. A. Randall (Boston), R. R. James (Central Virginia) and C. H. Davenport (El Dorado). Appointees to the Membership Committee were: T. E. Drisko, G. R. Pole, F. P. Lasseter and J. H. Vergilio. A. E. Chute was appointed to replace H. Pforzheimer on the Public Relations Committee. D. E. Wollscheid, H. L. Cook and P. R. Haas, Jr., were placed on the Suspense List because of their having entered the Armed Forces. The Secretary reported that financial statement had been received covering the White Sulphur Springs meeting. This showed a surplus from this meeting of $522.90 which was voted to be credited to the Institute Meetings Account.

The Council of the Institute met at the Hotel President in Kansas City, Mo., May 13, 1951. Following the approval of minutes of previous meetings, the first item of business was the discussion of the most recent draft of bylaws as prepared by the Constitution and Bylaws Committee. A few minor modifications were suggested and recommended to the Committee. Upon recommendation of the Student Chapters Committee a charter was granted for the formation of a student chapter at Stanford University, and also for the formation of a student chapter at Seattle University. Interim reports were presented to Council by the Student Chapters Committee, the Chemical Engineering Education Projects Committee and the Committee on Standard System of Symbols and Nomenclature Covering Unit Operations of Chemical Engineering.

The Auditor's report for 1950 was received and approved.

Upon recommendation of the Program Committee meetings of the Institute were approved as follows: At Atlanta, Ga., Mar. 16-19, 1952, at Toronto, Canada, April 27-May 2, 1953, and at St. Louis, Mo., Dec. 133-16, 1953.

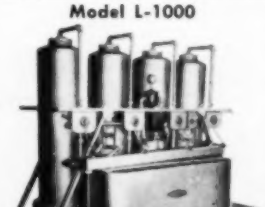
The Institute was represented by invitation at a meeting of the Federal Civil Defense Administration in Washington, D. C., by T. H. Chilton, G. Armistead, W. G. Whitman, E. P. Stevenson and H. C. Vernon. N. A. Shepard was appointed to replace F. J. Curtis on the Engineering Manpower Commission of EJC.



Problem Assigned Penfield: Raw well water of 347 PPM total hardness (calculated as $CaCO_3$) and 187 PPM alkalinity, methyl orange, as well as considerable hydrogen sulphides, needs to be conditioned for use as follows: 1300 gph for boiler feed water and sanitary purposes; 100 gph for use as make-up water for a condenser coolant; and 2500 gph for a process requiring exceptionally high purity water.

"Planned Purity" Solution: Aerated raw water is passed through Sand Filter (A) to remove colloidal sulphur (precipitated by aeration), then through Softener (B), at which point water of satisfactory softness for sanitary purposes is drawn off. Approximately 3000 gph of softened water passes on to large Cation Column (C) where the cations are removed and the 187 PPM of alkalinity are converted to carbonic acid which can be blown from the water into the Degasifier (D) as carbon dioxide. The degasified water then is pumped through the Sand Filter (E) and on to the Anion Column (F). However, provisions are made (1) for combining water taken from the large Cation Column with equal parts of water taken from the Softener to make an ideal blend for boiler feed use; and (2) for drawing off 100 gph of water demineralized down to approx. 20 PPM total solids, which with small additions of caustic soda is ideal for use as make-up water for a condenser coolant. The remaining water passing through this multiple-use conditioning system goes on to a battery of Demineralizing Units (G) which deliver approximately 2500 gph of the exceptionally high purity water (conductivity of 1,000,000 ohms) required in the plant's process.

Model L-1000



Pictured above is a Penfield Four Column Demineralizer with a capacity of 1000 gals/hr. In comparison to distilled water costs, Penfield Industrial Demineralizers provide savings as high as 85%, and in one reported instance cut costs 98%. No heat or steam power is ever required and units are ready for immediate operation on arrival at site. Send for "Penfield Pays" folio giving specifications of all Penfield Demineralizing units — from 10 gals/hr. to 10,000 gals/hr.

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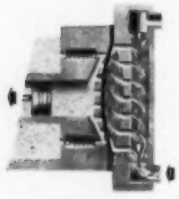
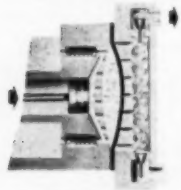


INTAKE STROKE



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- NO STUFFING BOX OR RUNNING SEAL
- HYDRAULICALLY-BALANCED DIAPHRAGM SEAL
- POSITIVE DISPLACEMENT PISTON MEASUREMENT
- FLOW RATE ADJUSTABLE WHILE IN OPERATION
- OIL-BATH LUBRICATION OF ALL MOVING PARTS
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Lapp PULSAFEEDER

PISTON-DIAPHRAGM CHEMICAL PROPORTIONING PUMP

WRITE for Bulletin 262 with complete description and specifications.

LAPP INSULATOR CO., INC., PROCESS EQUIPMENT DIVISION, 411 MAPLE STREET, LE ROY, N. Y.

(*News continued from page 40*)

TEXAS STILL EXPANDING; GROWING CHEMICALLY

A new era of chemical development and expansion is predicted for the Texas Gulf Coast, where plant and equipment investments already approach $1,000,000,000, according to Frederick A. Buechel, economist and research specialist, and head of the Houston Chamber of Commerce industrial research department. Dr. Buechel, for 17 years assistant director and statistician in the University of Texas' bureau of business research, has just completed a survey of the expanding chemical industry.

His report included the belt of land extending about 100 miles inland from the Gulf Coast and extending from Lake Charles, La., to Brownsville, Tex.

The total estimated value of chemical plants in the Gulf Coast area is estimated at $750,000,000, Dr. Buechel reported. Plant expansion during 1951 and 1952 planned by 16 of the 53 reporting plants in his survey totaled $100,000,000.

Survey figures do not include construction or expansion of such plants as Shell, Carthage Hydrocol and Ethyl Corp., which according to announcements, intend to expand their plants by approximately $80,000,000. Nor do they include investment in some related industries—$80,000,000 Reynolds metal plant under construction at Corpus Christi, nor Alcoa's $15,000,000 expansion at Fort Lavaca.

The average investment per worker in the chemical plants of the Gulf Coast is $30,000, with the number of workers totaling nearly 26,000.

USE OF FIBERGLAS TAPE EXPLAINED

A new tape made of glass fibers which is so strong that it has in many cases replaced steel strapping for packaging was demonstrated May 17 by the Industrial Tape Corp. at its plant in New Brunswick, N. J. This Fiberglas reinforced tape has the property of a high tensile strength of 200 lb. per inch of width. It is made with crepe paper laminated with approximately 45 glass threads to the inch of width and is coated with a stain-resistant adhesive.

This and other pressure-sensitive tapes—cellophane, acetate fiber, paper, electrical, cloth, and general-purpose tapes—are being given considerable study these days because of the applications of tape in war industries. For example, tape is used to prevent moisture from disabling detonators in hand grenades; for preventing rust and corrosion on airplanes and tanks and for many other uses in plant maintenance and operation in the electrical, automotive, textile and packaging industries.

NEW ISSUE OF E.C.P.D. GUIDANCE MANUAL

A guidance manual intended for engineers who are aiding young men interested in the engineering profession was published recently by the Engineers' Council for Professional Development, New York, N. Y. The 15-page pamphlet, prepared by the E.C.P.D. Guidance Committee, urges members of local engineering societies and sections and chapters of national engineering societies to establish guidance committees to aid high school pupils to determine whether they are qualified for careers in engineering. The present critical engineering manpower shortage emphasizes the need for guidance of the type indicated in this manual.

The manual explains briefly how to organize advisory committees and how to select committee members. The manual contains suggestions for working with high schools and secondary school students and lists aids especially useful in counseling high school boys.

The guidance manual is supplemented by an appendix, "Shall I Study Engineering?" which is a questionnaire to be filled out by the student for use of the engineer who is advising him.

Copies of the manual with questionnaire may be obtained from E.C.P.D., 29 West 39th Street, New York 18, N. Y. Price of combination, 20 cents. Cost of manual purchased separately, 15 cents. The price of the questionnaire, 10 cents. A deduction of 25 per cent for purchases of 25 or more is allowed.

PROFESSORSHIP NAMED FOR CAROTHERS

An annual research professorship in chemistry has been established at Harvard University by the Du Pont Co. in honor of the inventor of nylon.

The professorship is named for the late Dr. Wallace Hume Carothers, who headed the research group which created nylon. The professor holding the appointment to this position each year will be freed from all teaching and administrative duties at the University in order to spend his time entirely on the direction of research in chemistry at the postgraduate or postdoctoral level.

Du Pont is making an annual gift of $15,000 for five years to the University to support the professor and his research.

Dr. Carothers served as an instructor at Harvard from 1926 to Feb. 6, 1928, when he joined the Du Pont Co. It was while at Harvard that Carothers became interested in research on the synthesis of long-chain polymers.

(More News on page 52)

Protect It with Fansteel Tantalum Equipment!

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LOCAL SECTION NEWS

NEW JERSEY

A morning session on Filtration and an afternoon session of general technical papers marked the second all-day meeting at the Essex House, Newark, N. J., May 8. More than 400 chemical engineers attended. Shelby A. Miller, associate professor of chemical engineering at the University of Kansas, Lawrence, Kan., opened the sessions with a discussion on "Recent Advances in Filtration Theory." Miller reviewed the whole field of filtration, calling it a phenomenon of unsteady state of fluid dynamics, and ended his paper with the words that while the rigorous mathematical approach to the operation yielded completely unsolvable equations, that we must "acquiesce that the mathematical relationships which we today call the theory of filtration aid materially in the comprehension of this important operation and constitute a sound, reliable guide to its effective practice."

E. G. Smith of the Equipment Development Co., Inc., spoke on Fabric Filter Media, and considered all the various types of fabric media available and their relationship to filtration problems. He also described new fabric constructions, and described a new fabric which he said was designed to reverse the usual pattern of flow through filter cloth which almost all the filtrate passes through the strands and not through the apertures. The new fabric is made of plastic yarn of extremely high twist, and 98% of the filtrate was found to pass through the apertures. Longer life in actual plant operation was another advantage, he said. Other papers in the Filtration symposium were by H. P. Grace of Du Pont Co. who spoke on "What Type Filter and Why," and "Preparation of Slurries to Improve Filtration and Filtration Rates," by C. Fuhrmeister of Oliver United Filters, Inc.

Other speakers on the general technical program were M. A. Coler of Markite Co. and S. Lauren of C. J. Osborn Co. who spoke on "Alkyd Resins as Engineering Materials"; G. E. Shriver of U. S. Rubber Co. on "Some Chemical and Engineering Aspects of Cold Rubber Manufacture"; T. P. Forbath of Chemical Construction Corp. on "The New Sulfuric Acid Manufacturing Process"; and G. N. Harcourt, Buflovak Equipment Division on "Atmospheric and Vacuum Drum Drying."

At the May 8 meeting the following persons were chosen as section officers for the coming year:

Chairman—G. C. Keeffe, Newark College of Engineering
Chairman-elect—T. H. Kelly, Bakelite Corp.
Secretary—E. P. Foster, Du Pont Co.
Treasurer—J. D. Stell, Rutgers University
Executive Committee—F. J. VanAntwerpen, Chemical Engineering Progress; D. D. MacLaren, Standard Oil Development Co.; G. L. Berry, Calco Chemical Division; W. E. Keppler, Merck & Co.

These men assumed duties of the indicated offices June 1, 1951.

Reported by E. P. Foster

SOUTH TEXAS

Approximately 89 members and guests of this Section visited the Dow Chemical Co. at Freeport, Tex., April 20. After a short orientation program there was a choice of two inspection trips: (1) the "magnesium from sea water" process and (2) a combined inspection of the new ammonia plant and the styrene plant. The inspection trips were followed by a dinner and a talk by William C. Ford on the subject, "The Use of Psychological Tests in Personnel Development."

Dr. Ford founded the Psychological Service Institute in Houston in 1948 which serves as consultant for industry in this area. He described in some detail the procedures used at the Dow plant for which he is consultant.

Members visited the Engineering Laboratories of Rice Institute on March 30. The inspection trip was followed by a social hour and dinner after which John W. Tukey of Princeton University spoke on the subject "Application of Statistical Procedures to Chemical Engineering Problems."

Dr. Tukey's talk covered short-cut methods for testing the reliability of scientific data.

Reported by Henry D. Foster

OKLAHOMA

This Section heard J. Paul Jones discuss the relationship between engineers and the United States Patent system in Bartlesville, May 17. Mr. Jones, a patent attorney for the Phillips Petroleum Co., brought out the importance of the patent system in encouraging the disclosure of inventions to the public.

Reported by H. M. Hawkins

CHICAGO

The annual meeting was held May 16 at the Western Society of Engineers suite, with 64 present for dinner. The business included the adoption of a new constitution and bylaws for the Section, and the election of officers for the coming fiscal year as follows:

Chairman .....D. A. Smith
Vice-Chairman.....E. N. Mortenson
Secretary.....J. R. Blizzard
Treasurer.....W. H. Congleton
Director.....H. L. Pelzer

Following the business meeting, V. C. Searle, Commanding Officer of the U. S. Army Chicago Chemical Procurement District, spoke on "The Rehabilitation of the Japanese Chemical Industry." Col. Searle was formerly an officer in General MacArthur's occupation forces in Japan. His talk gave a first-hand insight into Japanese industry, economy, and way of life, and was illustrated by color slides.

This was the final meeting of the season.

Reported by Thorpe Dresser

PITTSBURGH

E. A. Kelly, process engineer from Hydrocarbon Research, Inc., was the principal speaker at the closing meeting of the season, held May 2 at the College Club. The occasion was the annual "Junior Member Night," sponsored by the Junior Committee, with J. K. Rice as chairman.

At the business session held during this meeting, the following officers for the 1951-52 season were elected:

Chairman.....F. O. Calhoon
Vice-Chairman.....Eugene Ayres
Secretary.....C. A. Bishop
Treasurer.....J. G. Bradshaw

The speaker of the evening covered the general design basis of the Carthage Hydrocol plant at Brownsville, Tex., and described the facilities included. Also discussed were some of the unusual problems encountered in the design and initial operation of this commercial synthetic liquid fuels plant.

At a previous dinner meeting held at the College Club of Pittsburgh, members and guests of this section heard Labor's point of view in management-labor relations. The speaker was

Marvin J. Miller, research associate, United Steel Workers of America, C.I.O. Mr. Miller, who possesses an academic background in economics and statistics, discussed "Organized Labor as an Economic Stabilizer." The historical development, objectives and present policies of the U.S.W. were described.

Reported by Hugh L. Kellner

ST. LOUIS

The Section held its annual joint dinner with the National Association of Corrosion Engineers and officers of the St. Louis Engineers Club, April 19, at the Forest Park Hotel. After the dinner, the group of 53 assembled with the Engineers' Club membership at the Club auditorium to hear Kent R. Van Horn discuss "Industrial Applications of Aluminum." Dr. Van Horn is an associate director of research for Aluminum Company of America.

He presented a summary of the characteristics, properties, and applications of the various commercial cast and wrought alloys. The functions of the various alloying elements and their effects on the properties of the alloys were described. Emphasis was placed on applications in the chemical industries.

Reported by A. T. Pickens

NEW YORK

At the annual business meeting held May 24, 1951, at the Brass Rail Restaurant, the following officers were elected for next year:

Chairman—William D. Kohlins, Buffovak division, Blaw-Knox, New York.
Vice-Chairman—Howard L. Malakoff, Cities Service Research & Development Co., New York
Treasurer—Clifton C. Sutton, General Foods Corp., Hoboken, N. J.
Secretary—Morgan M. Hoover, Chemical Engineering, McGraw-Hill, New York
Councilor-at-Large—Francis B. White, Foster-Wheeler Corp., New York

Reported by L. C. Johnston

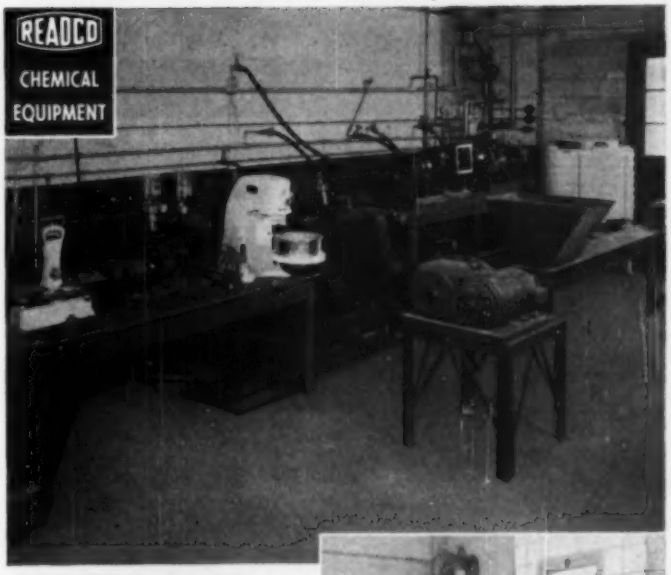
BOSTON

(Ichthyologists)

This Section held its annual election of officers May 11, 1951. The following were chosen for the 1951-52 season:

C. A. Stokes—Godfrey L. Cabot, Inc., Boston
J. Edward Vivian—Mass. Inst. of Technology, Cambridge
Randolph Antonsen — Godfrey L. Cabot, Inc., Boston
Peter Rinaldo—Dewey & Almy Chemical Co., Cambridge
A. W. Fisher, Jr.—A. D. Little, Inc., Cambridge, Mass.

Reported by Randolph Antonsen



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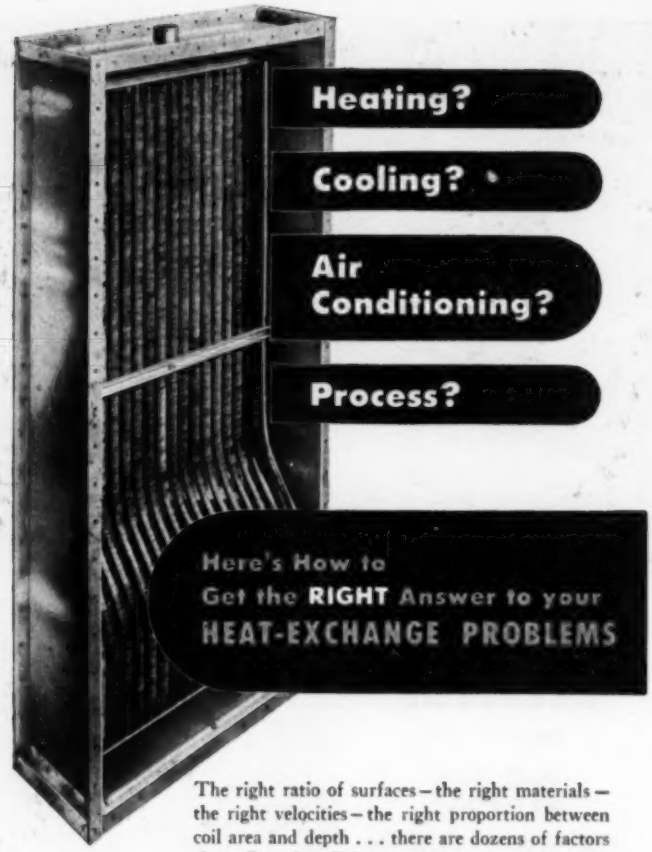

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DETROIT JUNIOR GROUP

This Section held a meeting May 9, 1951, in the Junior Room of the Rackham Memorial. H. F. Vieweg, assistant to the technical director of Tire Manufacturing for the U. S. Rubber Co., presented a talk entitled, "Organization of a Quality Control Program." In his initial remarks, Dr. Vieweg stated that all manufacturing concerns have some sort of a product quality control program. He then discussed the organization and operation of a systematic approach to the control of variability as associated with a statistical quality control program.

Officers for the 1951-52 season are:

Chairman—W. W. Jones, Detroit Sulphite Pulp and Paper Co.
Vice-Chairman—D. L. Miller, Sharples Chemicals, Inc.
Secretary—T. J. Carron, Ethyl Corp.
Treasurer—B. G. Hamnett, Parke Davis & Co.
Members-at-Large—R. E. Cavanaugh, Sno-Flake Products Co.; L. R. Chrzan, Ethyl Corp.

Reported by W. W. Jones

KNOXVILLE-OAK RIDGE

At the May 7, 1951, meeting D. C. Lewis, administrative fellow, Carbide and Carbon organic synthesis fellowship, Mellon Institute, spoke on "Some Consequences of Industrial Research." He emphasized the necessity for research in industry and illustrated some of its consequences by following the history of the various companies of Union Carbide and Carbon Corp. Mr. Lewis also showed a color motion picture made at the Mellon Institute entitled "Glimpses of a Range Finding Toxicity Study." The meeting was attended by 22 members and a door prize consisting of a pocket slide rule was awarded.

The Seminar Program during 1951 has been:

Harold J. Garber, University of Tennessee, "Infrared Radiant Heating," an example of combination of theoretical principles with experimental data to improve the design of commercial equipment used principally in the baking of finishes

E. E. Stansbury, University of Tennessee, "Some Applications of Solid State Reactions," introducing chemical engineers to recent advances in the study of solid state reactions and their role in stability, corrosion resistance, and thermal treatment of metals

G. P. Smith, Oak Ridge National Laboratory, "Surface Structure and Reaction Rates," discussing recent studies of the influence of crystal orientation on the rates of chemical reactions occurring on metal surfaces, showing how these observations have conflicted with formerly well-established theories, and using examples selected from such phenomena as catalysis, oxidation, and lubrication.

Reported by H. F. Johnson and W. K. Stromquist

SOUTHERN CALIFORNIA

This Section held its monthly dinner meeting April 10 at the Union Oil Refinery cafeteria, Wilmington, Calif. T. H. Chilton, President of American Institute of Chemical Engineers and technical director, development engineering division, engineering department, Du Pont Co., discussed "Units—Scientific and Technical." He reviewed the appropriate "units" in which engineers can act most effectively in service to the profession and the nation. In the course of this talk an outline of the activities and objectives of such organizational "units" as the Engineers Joint Council, the National Society of Professional Engineers, and the Engineers Council for Professional Development was presented.

An additional spe ial attraction, "Annual Student Night," found some 48 senior students from the chemical engineering departments of the University of Southern California, University of California at Los Angeles, and California Institute of Technology attending as guests of the local section. There were 90 local section members present.

The Los Angeles refinery of the Union Oil Co., welcomed the students some two hours prior to the scheduled meeting time and during the interim conducted plant tours through the refinery, laboratories, and allied facilities.

Reported by Gale S. Peterson

STUDENT CHAPTER MEETING AT PULLMAN

Washington State College was host May 10 and 11 to the third annual Northwest Regional Meeting of A.I.Ch.E. Student Chapters held since the war. Seventy delegates from Gonzaga U., U. of Idaho, Montana State, Oregon State, Seattle U., Stanford U., U. of Washington, and Washington State attended the sessions.

J. A. Davidson and R. L. Nickelson of Montana State College were awarded ten dollars and first prize for their paper, "Design and Construction of a Pilot Plant Continuous Rectification Column." H. Brammer and G. Nickelson of the University of Idaho took second prize and five dollars with "Chlorination of Benzene in a Continuous Reactor." Honorable mention went to T. H. Rockwell of Stanford University for his paper, "The Demand for Chemical Engineers in Industry." Seven other papers were also presented.

Guest speakers were J. H. Hull, chief of process development, Crown-Zellerbach Corp., who spoke on waste sulfite liquor, and Lamar Bupp from the Richland plant of General Electric Co., who spoke at the banquet. His topic was "The Young Engineer in Industry."

Reported by Harry Stern

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FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee

Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Rochester, N. Y., Sheraton Hotel, Sept. 16-19. 1951.

Technical Program Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.

Annual — Atlantic City, N. J., Chalfonte-Haddon Hall Hotel, Dec. 2-5, 1951.

Technical Program Chairman: Frank J. Smith, Pan American Petroleum & Transport Co., 122 East 42nd St., New York 17, N. Y.

Atlanta, Ga., Atlanta Biltmore Hotel, Feb. 17-20, 1952.

Technical Program Chairman: H. E. O'Connell, Ethyl Corp., Box 341, Baton Rouge, La.

French Lick, Ind., French Lick Springs Hotel, May 11-14, 1952.

Technical Program Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.

Chicago, Ill., Palmer House, Sept. 4-6, 1952.

Technical Program Chairman: George C. Lamb, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.

Technical Program Chairman: R. L. Savage, Dept. Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Annual—St. Louis, Mo., Dec. 13-16, 1953.

SYMPOSIA

Maintenance

Chairman: D. E. Pierce, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Rochester, N. Y.

Industrial Applications of Photography

Chairman: Carl Gath, Eastman Kodak Co., Kodak Park Works, Rochester, N. Y.
Meeting—Rochester, N. Y.

Round Table Discussion of Chemical Engineering Education

Chairman: W. E. Gift, Tennessee Eastman Corp., Kingsport, Tenn.
Meeting—Rochester, N. Y.

Opportunities in Sales for Chemical Engineers

Chairman: F. J. Curtis, Monsanto Chem. Co., 75 Rust Bldg., 1001 15th St. N.W., Washington 5, D.C.
Meeting—Atlantic City, N. J.

Chemical Engineering Fundamentals

Chairman: W. C. Edmister, Chem. Eng. Dept., Carnegie Inst. of Tech., Pittsburgh 13, Pa.
Meeting—Atlantic City, N. J.

Effective Speaking

Chairman: L. P. Scoville, Jefferson Chem. Co., 711 Fifth Ave., New York 22, N. Y.
Meeting—Atlantic City, N. J.

Vacuum Engineering

Chairman: W. W. Kraft, The Lummus Co., 385 Madison Avenue, New York, N. Y.
Meeting—French Lick, Ind.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

WESTERN NEW YORK

This Section convened April 12 at the Red Coach Inn, Niagara Falls, N. Y., for its monthly dinner meeting. Approximately 52 members and guests attended the meeting.

The following were elected officers for 1951-52:

Chairman—Earl C. Mirus, National Aniline
Vice-Chairman—J. E. Troyan, Mathieson
Secretary-Treasurer—Bill C. Greenwald, Du Pont
Directors—Art L. Cerda, Union Carbide; Bill J. Mitchell, Linde Air; Axel K. Heilborn, Niagara Alkali

The speaker of the evening, J. B. Jones, DuPont Experimental Station, Wilmington, Del., presented his paper on "Scale-up of Semi-Works Distillation Equipment."

The annual Ladies' Night was held May 10 at the Dutch Terrace Room, Hotel Stuyvesant, Buffalo. The speaker was M. G. deNavarre, an associate of Beauty Counselors, Inc., Detroit, Mich. This was the final meeting of the 1950-51 year.

Reported by J. E. Troyan

CHARLESTON, W. VA.

A general meeting of this Section was held at the Charleston Recreation Center, April 17, 1951. This is the last technical meeting of the 1950-51 season.

The nominating committee proposed the following slate of 1951-52 officers:

Chairman—D. J. Porter, Westvaco
Vice-Chairman — Roland Voorhees, Carbide and Carbon
Secretary—George Connolly, Carbide and Carbon
Treasurer—R. E. Soden, Monsanto
Member-at-Large — John Crawley, Du Pont

The speaker of the evening was J. M. Bright, editor-in-chief of Modern Materials Handling, who spoke on that subject. Mr. Bright commented that materials-handling was a methods study applied to the flow of materials through a plant. He defined operating efficiency as largely skill in handling materials.

Mr. Bright gave several interesting examples illustrating various types of materials-handling problems. The emphasis is on mechanization using every available tool including television. The speaker also commented on a new trend toward customer-owned containers with specifications to the vendor on methods of packing and delivery, physical form of material, etc.

The last meeting this season was the annual business and dinner meeting on May 25 at the Kanawha Country Club.

Reported by M. C. Guthrie, Jr.

EL DORADO

A dinner meeting, attended by 53 members and guests, was held at the Albert Pike Hotel in Little Rock, Ark., on April 20. Robert E. Neiman, manager of the Southern Bearing Service, Inc., of Little Rock, talked on "Anti-Friction Bearings." Mr. Neiman covered the reasons for using antifriction bearings and explained the part they are playing in modern industry. Following the talk, two movies on the manufacture and maintenance of antifriction bearings were presented.

On the morning of April 21, 40 members of the section were the guests of the Reynolds Metals Co. for a 3½-hr. plant tour through its Hurricane Creek alumina plant located near Bauxite, Ark. This plant processes Arkansas bauxite ore to alumina by a modified Bayer process.

Reported by R. L. Alexander

ROCHESTER

The meeting on May 16 was held at Lorenzo's and was the annual banquet which marked the close of the 1950-51 season. Approximately 100 attended.

Election results were announced as follows:

Chairman.....John Patterson
Vice-Chairman.....R. R. Ross
Secretary.....Irving Siller
Treasurer.....William Kaiser
Directors.....John H. Folwell
Gordon Calderwood

James Sterner, the speaker, pointed out industry's responsibility in maintaining safe working conditions and told of information now available on limiting concentrations of hazardous chemicals which makes it possible to set up safe working procedures. He also spoke of beryllium and some of the difficulties arising from its use. Dr. Sterner predicted that noise and radiation would become important industrial problems in the near future.

Reported by O. J. Britton

CLEVELAND

The April 24 meeting of this Section was held at Fenn College. W. W. Schafer gave a short after-dinner talk, which reviewed the history of the Lubrizol Corp.

The main speaker of the evening was J. B. McMahon of Republic Flow Meter who addressed the group on the subject "Instrumentation as Applied to the Chemical Industry."

The regular May meeting was held May 22, 1951, at the research laboratories of the Standard Oil Co. of Ohio. A dinner at the laboratories will be followed by a tour of the facilities.

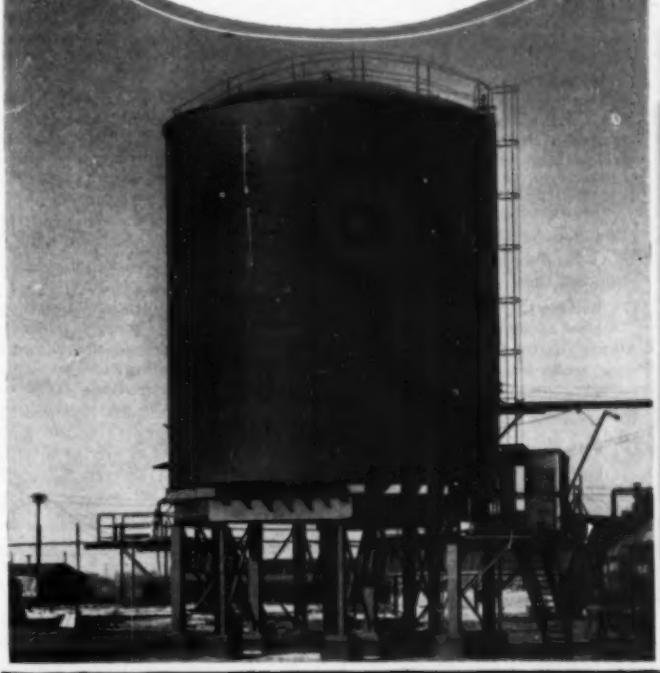
Reported by G. H. Metzger

Store 77.7% sulphuric acid in Horton welded steel tank

The tank shown below is located at a chemical plant in northern Illinois. It's 31½ ft. in diam. by 35 ft. high.

77.7 per cent sulphuric acid manufactured at the plant is pumped into the tank at the rate of 150 tons per day (tank capacity is 1500 tons of acid). Since the tank is mounted on a grillage 15 ft. above the ground, acid flows from it by gravity into tank cars or tank trucks for delivery to the steel mills. The acid is used there principally in pickling steel.

The self-supporting umbrella roof shown below is popular for acid storage tanks because, when it is used, there are no supporting columns inside the tank. When you need Horton welded steel storage tanks for the storage of acid, or any other liquid, get an estimate from our nearest office.



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Detroit 26.....1546 Lafayette Bldg.
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Houston 2.....2154 National Standard Bldg.
Los Angeles 17...1541 General Petroleum Bldg.
New York 6.....3322—165 Broadway Bldg.
Philadelphia 3....1640—1700 Walnut St. Bldg.
Salt Lake City 4.....560 West 17th South St.
San Francisco 4.....1536—200 Bush St.
Seattle 1.....1360 Henry Bldg.
Tulsa 3.....1643 Hunt Bldg.
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LETTER TO THE EDITOR

"A YOUNG MAN LOOKS AT HIS 'PROFESSION'"

Sir:

I have read .... ("C.E.P." Feb. 1951, P. 17) "A Young Engineer Looks at His 'Profession'," by J. B. Weaver. Mr. Weaver has marshalled impressive documentation to support his contentions, but I think he has overlooked a most significant source of information. This is not surprising, since the engineer is not accustomed to consulting T. C. Mits, The Celebrated Man in the Street. In this particular case, however, T. C. has what seems to me the last word on the subject, since it is he who gives or withholds the coveted "professional status."

After reading Mr. Weaver's article I asked the opinions of a few people who fall in the Mits category, and their answers did not correspond exactly with Mr. Weaver's conclusions. It is true that T. C. Mits holds the "learned professions" in higher regard than he does engineering, but his reasons are neither intellectual nor abstract. The fact is that clergymen, physicians, and attorneys solve personal problems of vital importance that arise every day for someone, and at least once for everyone. What service has the engineer to offer the individual which can compare in that individual's mind with comforting his agonized spirit, healing his sick body, or guiding him through a labyrinth of legal procedure?

I believe that this direct, personal service is the key to the high esteem in which T. C. Mits holds the "learned professions." I further believe that the term "professional" has been defined so narrowly by usage that it is impossible for engineers to qualify in the same sense that the word is applied to ministers, doctors, and lawyers. I do not think that oaths, licenses, or formal codes of ethics can change this.

Does this mean, then, that engineers can never hope to be more than highly educated craftsmen in the eyes of T. C. Mits? I think not. The engineer's vital creative function in society entitles him to public respect, different from that accorded the "learned professions," but no less honorable because it lacks the same emotional aspects. Individual engineers now receive this respect, and patience and perseverance will obtain it for engineers as a group. After all, the "learned professions" did not achieve their high position overnight and without effort.

Up to this point I have purposely omitted referring to "public service" and "social implications of technical progress," which seem to concern Mr. Weaver very much. I, too, am concerned about these things, but as a citizen rather than an engineer. As a citizen I have a share in the responsibility for the use or misuse of technological advances, but the fact that I am a technical specialist does not make my value judgments any better than those of T. C. Mits.

As to engineers' lack of interest in public service, housing projects and public health improvements cost money, even if engineers could and would work for nothing. Engineers to direct and assist in these undertakings will be available as soon as T. C. Mits decides he wants them enough to finance them.

The engineer will probably never receive the same kind of public esteem given to the physician, but in time T. C. Mits may be persuaded to widen his definition of "professional" to include the honorable status to which the engineer's achievements do entitle him. Toward this end engineers should continue to build a tradition of increasing levels of competence and integrity as a group, and civic responsibility and initiative as individuals.

Salt Lake City, Utah

R. L. Rorschach

NEWS (*Continued from page 45*)

CHEMICAL SAFETY DATA SHEET AVAILABLE

Chemical Safety Data Sheet SD-38 on ethylene oxide has recently been published by the Manufacturing Chemists' Association, Inc., in connection with its program to provide essential information on safe use and handling of hazardous chemicals. Among the precautionary measures discussed are those designed to prevent fire and explosion resulting from the variable physical state of ethylene oxide. Also covered are the common dangers involved in handling storage, waste disposal, and loading and unloading of tank cars and drums. All data are cross-referenced and documented in relation to warning labels, national fire codes, and Bureau of Explosives, American Standards Association, and Interstate Commerce Commission regulations.

This data sheet of 18 pages may be purchased at 30 cents a copy from the Manufacturing Chemists' Association, Inc., 246 Woodward Building, Washington 5, D. C.

PEOPLE

S. Philip Marcus was recently made assistant production manager, Westvaco chemical division, Food Machinery and Chemical Corp., with headquarters in New York. He was previously assistant to the manager of Westvaco's South Charleston (W.Va.) plant.

Simultaneously **Robert A. Bondurant, Jr.,** has joined Westvaco's production staff in New York. Formerly executive vice-president of Michigan Chemical Corp., St. Louis, Mich., Mr. Bondurant had worked on various assignments at Westvaco's South Charleston (W. Va.) plant between 1936 and 1943.

Waldo L. Semon, director of pioneering research for the B. F. Goodrich Co., addressed the Engineers' Club of the Virginia Peninsula, May 10, on "American Rubber—Its History and Future."

Earl R. Englert, formerly a chemical engineer for the Monsanto Chemical Co., Dayton, Ohio, is now an operating engineer for the Girdler Corp., Louisville, Ky.

Asoke Kumar Gupta, formerly associated with the American Potash & Chemical Corp., Trona, Calif., is now an international trainee for Joseph E. Seagram & Sons, Inc., Louisville, Ky.

Walter H. Harte is now a process engineer for the Jefferson Chemical Co., New York, N. Y. He was formerly associated with the Minute Maid Corp., Orlando, Calif.

Warren H. Hay, formerly a chemical engineer for the Monsanto Chemical Co., Everett, Mass., is now associated with Sylvania Electric Products, Inc., Salem, Mass.

Hugh B. Henderson, formerly a plant manager for the Jet Manufacturing Corp., Los Angeles, Calif., is now a junior engineer for the Tide Water Associated Oil Co., Ventura, Calif.

Frank C. Fowler is now a self-employed consulting engineer in Kansas City, Mo. He was formerly professor of chemical engineering at the University of Oklahoma.

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CA Technical Topics

ALLOY TYPE 25-12

Norman S. Mott
Chief Chemist and Metallurgist

Alloy type 25-12 (CA22) is mainly a heat resisting alloy, although in the low carbon grade, with or without columbium or molybdenum, it is often used for its corrosion resistance. It is the most economical alloy for high temperature structural applications, such as tube supports, dampers and general furnace parts. In gas carburizing and bright annealing or hardening atmospheres its resistance is excellent and its resistance to high temperature air oxidation and to the corrosive action of high sulfur fuel flue gases is outstanding.

The 25-12S, 25-12SCb and 25-12SMo grades give excellent service in the sulfite pulp industry; and offer high resistance to nitric, phosphoric, dilute sulfuric and hydrochloric acids, as well as to organic acids such as citric, tartaric and lactic. 25-12S has better corrosion resistance than 19-9S, with carbon not being so critical. This holds for use in dilute sulfuric and hydrochloric acids at all temperatures, and in nitric acid at all concentrations and temperatures. In fact, in the boiling 65% nitric acid test 25-12S as cast is as good as 19-9S in the water quenched condition. The addition of molybdenum makes this alloy remarkably resistant, and its superiority in hot dilute sulfuric and hydrochloric acids over 19-9SMo is considerable. This suggests its use over 19-9SMo in some of the more exacting applications not necessitating the use of expensive FA-20 type alloy.

A.S.T.M. Specification B190-45T classifies the 25-12 alloy into two categories according to magnetic permeability: Type I, having a range of 1.05-1.7 and Type II, having a maximum of 1.05, after holding for 24 hours at 2000° F. and water quenching. Since strength and ductility vary inversely at high temperatures, Type I containing ductile ferrite is able to resist fracture due to sudden overloads by yielding slightly under these stresses, but it has relatively low creep strength. Type II is completely austenitic and has high creep strength under conditions of constant loading, but is not as resistant to sudden shock.

Of major importance in heat applications is the influence of structure on its properties. The amount, form and distribution of the carbides affect strength and ductility and are determined by the percentage of carbon present in the alloy, the temperature, and the time of holding. Of perhaps greater importance is the presence of ferrite in the structure. While it enhances ductility at elevated temperatures after short-time aging, it must be discounted if the alloy is to be exposed for extended periods at the intermediate temperature range of 1200-1700° F., as this range favors the formation of a sigma phase which is hard and brittle. Its presence may result in reduced strength, ductility, and especially thermal fatigue cracking resistance. Thus there is much less tolerance for suddenly applied stress overloading or rapid temperature changes. Continued service about 1700° F. precludes this sigma formation.

To estimate ferrite on the basis of chemical analysis the Alloy Casting Institute suggests the following formula:

$$R.F. = \frac{[\%Cr + 3\ (\%Si - 1)] - [\%C \times 16]}{\%Ni}$$

A ratio factor less than 1.7 denotes a negligible amount of ferrite or sigma and corresponds to the A.S.T.M. limit in permeability value of 1.05. A ratio factor of 1.7-1.85 denotes 2-7%, and a ratio factor above 1.85 denotes above 7% of ferrite or sigma.

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Cooper Alloy Materials Selection Chart—designed to help you choose the most economical alloy for any corrosive condition. This chart will save you money and save critical materials for national defense. Address your requests to Publicity Dept., The Cooper Alloy Foundry Co., Hillside 5, N.J.

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CHEMICAL CHIEFS IN N.P.A.

Thomas S. Nichols (right), deputy administrator, National Production Authority, U. S. Department of Commerce, congratulates Francis J. Curtis (center), and Kenneth H. Klipstein upon their being sworn in as key members of the NPA staff. Mr. Curtis takes the post of assistant administrator to head the Chemical, Rubber and Forest Products Bureau, and Mr. Klipstein takes the post of director of chemical division of the NPA. Mr. Curtis was 1949 President of A.I.Ch.E. Mr. Klipstein is on leave from Calco chemical division of American Cyanamid Co., and Mr. Nichols from Mathieson Chemical Corp.

Charles A. Stokes, director of research and development for Godfrey L. Cabot, Inc., Boston, Mass., since 1945, and **Lawrence W. Mims,** plant manager, Cabot retort chemical division, Gainesville, Fla., were among eight graduates of the University of Florida to receive the professional degree of chemical engineer at recent mid-year commencement exercise. Stokes' thesis was titled, "Sonic Agglomeration of Carbon Black," published in Chemical Engineering Progress, August, 1950, page 423. Mr. Stokes was graduated from the University of Florida in 1938, later attending M.I.T. where he became an instructor and assistant professor.

Mr. Mims, a graduate of the University in 1937, chose as his topic, "A Preliminary Survey for a Proposed Gum Naval Stores Plant."

Frank C. Evans, who has been director of Du Pont Co.'s service department for 16 years retired effective June 1. He joined Du Pont in 1915 as a chemist at the Repauno Works of the explosives department in Gibbstown, N. J. Following many assignments Mr. Evans returned to Wilmington in 1927 to become manager of the personnel division. In 1929 he became assistant director of the service department and in 1934 was made director. In 1911 he received his Master's degree from Bowdoin College, and from 1911 to 1915 was a graduate student in chemistry and an instructor at the University of Wisconsin.

George R. Bouffard, formerly of the Pure Oil Co., is now foreman of the hydrolyzing department of Procter & Gamble, Arlington Hights, Ill.

Foster Dee Snell, president of Foster D. Snell, Inc., New York firm of consulting chemists and chemical engineers, presented three papers before the Third World Petroleum Congress which was held at the Hague May 28-June 6, 1951. All three papers, written in collaboration with members of the Snell staff, are on different phases of detergents as they are produced from raw materials of the petroleum industry.

TEETER, LA CASSE WITH G. E. CHEM. DEPARTMENT

The appointments of **Robert L. Teeter** as manufacturing engineer and **Alfred R. LaCasse** as manufacturing analyst for the chemicals division of the General Electric Co.'s chemical department, were announced recently.

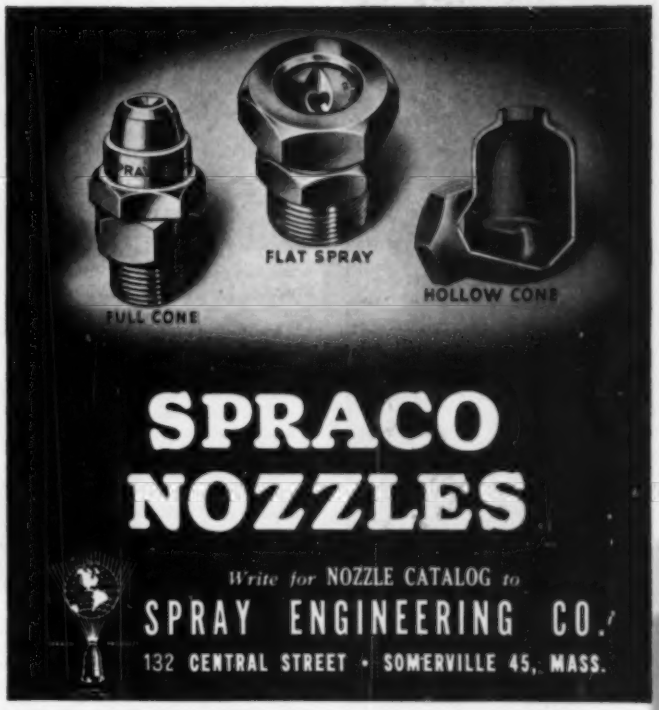
Mr. Teeter was formerly a chemical project engineer for Tennessee Eastman Corp., Kingsport, Tenn. He holds a B.S. in chemical engineering from Kansas State College, a Master's degree from the Virginia Polytechnic Institute, and a law degree from the University of Virginia.

Mr. LaCasse first went with the company in 1943 as an operating engineer in the phenol plant, ultimately becoming a process engineer. In June, 1949, he was assigned to a project entailing special economic studies. Since November of that same year and until his present appointment, he has been a process engineer for the resin, varnish, and compound plant. He holds a Bachelor's degree in chemical engineering from Iowa State College.

A. S. Gilliam plans to move from Baltimore to Kentucky this summer as production manager of Mathieson Hydrocarbon Chemical Corp. plant in Brandenburg. He resigned his position with Shell Oil Co., Inc., at the Houston (Tex.) refinery in May, 1950, to join the newly formed Mathieson Hydrocarbon Chemical Corp. He worked in Boston as a project engineer representing the firm with engineering contractors who were engaged to construct the new petrochemical plant in Brandenburg.

Ernest W. Reid, associated with Corn Products Refining Co., since 1943 when he joined the company as vice-president in charge of research and development and head of the chemical division, was recently elected president. He has been a member of the board of directors since 1947. Early in his career Dr. Reid was associated with the Mellon Institute and with the Carbide and Carbon Chemicals Corp., and subsequently became director of European sales for Union Carbide and Carbon Corp., and from his headquarters in Brussels and London had charge of introducing Carbide's new aliphatic organic chemicals to European markets. Still later he became a member of the Council for National Defense and following a period of association with E. R. Weidlein in establishing the chemicals branch of the Office of Production Management he advanced to the position of deputy director general for operation of W.P.B. From the University of Pittsburgh he received the Ph.D. degree in chemical engineering in 1931.

Charles Allen Thomas was recently elected president of Monsanto Chemical Co. and took office May 1. Dr. Thomas, who had been executive vice-president since 1947, is 51 years old. His career started with the General Motors Research Corp. in 1923. In 1926, with Dr. Carroll A. Hochwalt, now a member of Monsanto's executive committee, Dr. Thomas organized the Thomas & Hochwalt Laboratories at Dayton, Ohio, specializing in industrial research. Monsanto acquired the laboratories in 1936, and Dr. Thomas became central research director of the company. He was elected to the board of directors of Monsanto in 1942. In 1945, he was elected vice-president and technical director of the company and became a member of Monsanto's executive committee. On April 20, 1951, President Truman appointed Dr. Thomas to an eleven-man committee of scientists to help coordinate government and private scientific research and planning for defense. The group will advise Defense Mobilization Director Charles E. Wilson on top secret research in all the sciences.



A.I.Ch.E. MEMBERSHIP INFORMATION

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American Institute of Chemical Engineers
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New York 17, New York

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THE THERMAL SYNDICATE, LTD.
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W. N. Williams has been appointed operating vice-president of the Westvaco chemical division of Food Machinery and Chemical Corp. with headquarters in New York. Mr. Williams has been associated with Westvaco and its predecessor companies for more than 20 years having been successively manager of the Barium Products, Ltd., plant at Modesto, Calif.; manager of Western operations at Newark, Calif., and more recently vice-president of production at New York. **Robert J. DeLargey** has been named one of Mr. Williams' staff assistants. Prior to joining Westvaco, Mr. DeLargey was superintendent of Shell Chemical's Pittsburg (Calif.) ammonia plant and more recently assistant general manager of Grove Regulator Co. of Oakland, Calif.

Alan Porter Lee, consulting engineer of Morristown, N. J., has been elected an honorary member of Pi Tau Sigma, Pi Pi Chapter, at Brooklyn Polytechnic Institute. After the Initiation and meeting Mr. Lee addressed the chapter on "Process Equipment in the Glyceride Industries."

F. M. Mooma is now senior engineer with the Bechtel Corp., San Francisco, Calif. He was formerly job engineer.

John R. Bowman, head, department of research in physical chemistry, Mellon Institute of Industrial Research, Pittsburgh, Pa., was recently elected a councilor of the American Institute of Chemists. Dr. Bowman will serve in that capacity for three years.

Ralph L. Carr has been appointed manager of the technical service department of Mathieson Chemical Corp., Baltimore, Md. He will report to George P. Vincent, director of product development. Mr. Carr is the author of numerous papers and booklets on ammonia, caustic soda and chlorine, and was instrumental in developing the Mathieson open-width steamer used in texile manufacturing.

Lawrence K. Cecil was recently elected vice-president of Infilco Inc., Tucson, Ariz. He has been general sales manager of the company since August, 1950, and has been with the company for 25 years in the capacity of sales engineer and district manager. Previous to joining Infilco he was affiliated with the Oklahoma Medical School and the Oklahoma State Health Department. Mr. Cecil is a graduate of the University of Illinois.

John T. Ragsdale, Jr., has been named head of the newly formed market research and product development section of the organic chemicals division of Monsanto Chemical Co. He will be responsible for the development of intermediates other than resin intermediates. Mr. Ragsdale has been coordinator of technical service and market development for the organic division. Mr. Ragsdale joined Monsanto in 1919 as a production supervisor. Until 1933, when he was transferred to the technical service division, he was engaged in the development of new manufacturing processes. From 1941-43 he was assigned to Monsanto's Washington office. He is a director of the Commercial Chemical Development Association.

A. D. Miller, general manager of the synthetic rubber division of the Firestone Tire & Rubber Co. since 1947, has been named to the staff of J. N. Street, director of chemical laboratories of Firestone. Mr. Miller joined Firestone as a chemist in the general laboratory 17 years ago while still at college. He received a B.A. from Capital University in Columbus in 1935 and a degree in chemical engineering from Case Institute of Technology in 1940. Subsequently he was named head of the technical division of the Firestone-operated rubber reserve plant in Akron, and then technical manager for all of Firestone-operated synthetic rubber plants.

Morris B. Minkin is now a production superintendent for Maynard Plastics, Inc., Chelsea, Mass. He was formerly an assistant area supervisor in the fabric division of the Industrial Rayon Corp., Covington, Va.

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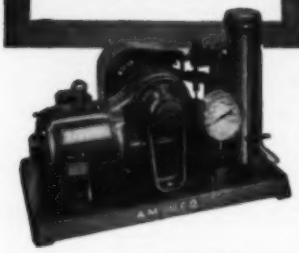

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George O. Curme, Jr., has been elected vice-president in charge of research of Union Carbide and Carbon Corp. and will head all the research activities of Union Carbide. Since 1948 (see C.E.P., June, 1948, p. 56) he has been vice-president in charge of chemical research for the corporation and for many years a vice-president of Bakelite Co., and Carbide and Carbon Chemicals Co. His research work on acetylene at the Mellon Institute of Industrial Research, resulted in the formation of Carbide and Carbon Chemicals Corp. He has been the recipient of many honors, among them the Chandler Medal from Columbia University in 1933, and the Perkin Medal, awarded by the Society of the Chemical Industry, in 1935. He attended Northwestern University, took a year of graduate study at Harvard and a doctorate at the University of Chicago.

Bachrach

R. R. WOLF, P. H. SEAVER NOW WITH BADGER

Mr. Wolf is now in the engineering and sales department of Badger Manufacturing Co. He is a graduate of the University of Pennsylvania and was previously associated with the Celanese Corporation of America, and Day and Zimmerman, Inc. For seven years he has been with E. B. Badger & Sons Co. in process engineering and sales.

Mr. Seaver is now in the engineering department. Since his graduation from Cornell University he has been associated with E. B. Badger & Sons Co. except for two years in the Navy as Lieutenant (j.g.) assigned to the heat-transfer section of the Bureau of Ships and more particularly to vapor compression and steam-type evaporators. While with E. B. Badger & Sons Co. he was connected with process engineering.

Erich R. Westfield has been assigned to the economic and correlation section of the research and development division of Houdry Process Corp., Philadelphia, Pa. Formerly with the Pan American Refining Corp., Mr. Westfield is a graduate of Vanderbilt University and received his M.S. at M.I.T. **H. Harold Bulkowski** has joined the development department and is assigned to the Atomic Energy Commission program. Formerly with Battelle Memorial Institute, Mr. Bulkowski is a graduate of Carnegie Institute of Technology and Ohio State University.

(*More About People on page* 59)

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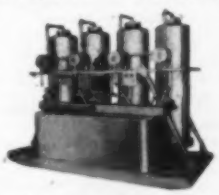

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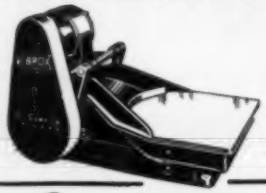

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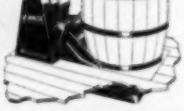

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Notice—Applications are invited for the post of Planning Engineer, Department of Industries, Ceylon. Applications should reach the Ceylon Embassy, 2148 Wyoming Avenue, N.W. Washington, D. C., before the 25th June, 1951. Applicants should be corporate members of a recognized Institute of Chemical or Mechanical Engineers, or possess equivalent or higher qualifications. Further particulars could be obtained from the Ceylon Embassy, 2148 Wyoming Avenue, N.W. Washington, D. C.

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Chemical Engineer—M.S., 1947, large Eastern university. Married, 31. Experience: design, development, and plant erection. Sigma Xi. Publications and patents pending. Desire design, development or research position. Box 6-6.

Project Engineer—Six years' unusually diversified experience: chemical plant design projects, operation, instrumentation, cost estimating, economic evaluations of organic, heavy and petroleum chemical plants. B.S.Ch.E., additional mechanical engineering, business administration courses. I.S.A. member. Energetic; successful performance record. Currently employed with major producer. Desire expanding opportunity with progressive organization. Box 7-6.

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NOTE: EMPLOYERS

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(*People, continued from page 57*)

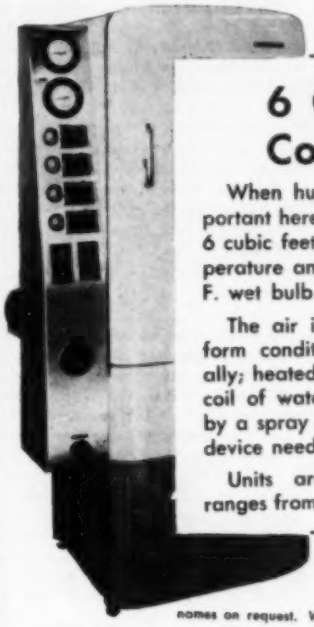
J. Fred Dudley has been advanced to assistant chief engineer of Commercial Solvents Corp., according to a recent announcement by Maynard C. Wheeler, vice-president in charge of production. Mr. Dudley's headquarters will be at the company's Terre Haute (Ind.) plant. Prior to joining Commercial Solvents' engineering division in 1943, Mr. Dudley was associated with the M. W. Kellogg Co. He is a graduate of Virginia Polytechnic Institute.

Frank J. Soday has resigned as research director of the Lion Oil Co. to accept the same position with the Chemstrand Corp. The latter is owned jointly by Monsanto and American Viscose and is presently building several plants in the South for the production of acrylic fibers and nylon.

John Griswold has resigned as professor of chemical engineering at Illinois Institute of Technology, to become full-time consultant to general chemical division, Allied Chemical & Dye Corp. He will be located in New York City.

Hugh S. Taylor, dean of the Princeton University Graduate School and former chairman of the university's department of chemistry, presented the 1951 Remsen Memorial Lecture of the American Chemical Society's Maryland Section, in Remsen Hall of Johns Hopkins, May 25.

John E. Swearingen has been elected to membership on the board of directors of Stanolind Oil and Gas Co., Tulsa, Okla. A native of Columbia, S. C., Swearingen has been with Stanolind since April, 1947. During most of that time, he has been in the company's general office in Tulsa. For 13 months, he was also manager of Stanolind's central division with headquarters in Oklahoma City. He returned to Tulsa in February of this year to begin a new assignment. Before joining Stanolind, he was with the Standard Oil Co. (Ind.) for eight years. He received an M.S. in chemical engineering from Carnegie Institute of Technology, Pittsburgh.



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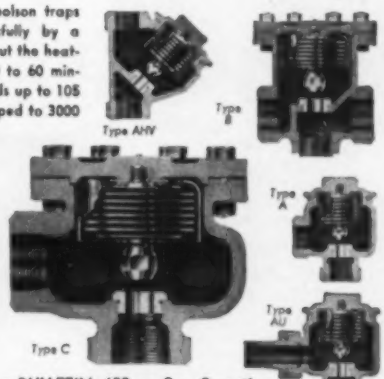

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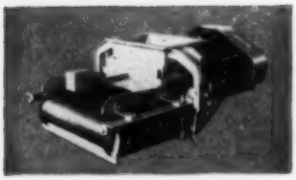

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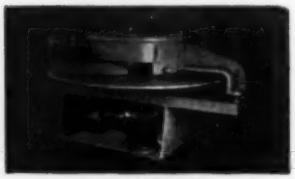

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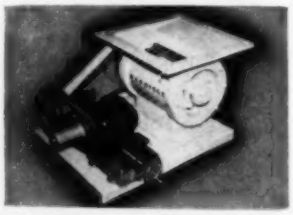

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HENRY HELLER RETIRES

Henry Heller, vice-president in charge of engineering of the Mutual Chemical Company of America is retiring effective July 1 after completing a 37-year association with the company. Back in 1914 he took the position of chemical engineer for the Mutual Chemical Company of America located in Jersey City. He had previously received a B.S. in chemical engineering from the University of Pennsylvania and had been employed by the American Sugar Refining Co., the Great Western Sugar Co. and the Billings Sugar Company of America.

O. P. Bergelin, associate professor of chemical enginering at the University of Delaware, has received a Fulbright scholarship through the U. S. Department of State and National Research Council to do research at a New Zealand volcanological observatory at Rotorua. He will aid the dominion government in seeking to harness the steam and hot water from underground. Dr. Bergelin has been on the University of Delaware faculty since early in 1946 and during that time has directed considerable research in the fields of fluid flow and heat transfer.

Hervey J. Skinner has retired from the organization of Skinner & Sherman, Inc. He has been a chemical consultant for more than 40 years. For 17 years he was with Arthur D. Little, Inc., and in 1921 he organized the firm of Skinner, Sherman & Esselen, Inc., which later became Skinner & Sherman, Inc.

Walter Crutchfield, consulting chemist and chemical engineer, has moved his office to Stony Mountain Lodge, Hendersonville, N. C. Mr. Crutchfield has 20 years' experience in rayons, cellulose products, heavy chemicals, waters treatment and stream pollution abatement.

Bernard W. Gamson has been appointed Director of the Research and Development Division of the Great Lakes Carbon Corporation at Morton Grove, Illinois. He was formerly Chief Process Engineer for Great Lakes with headquarters in Chicago. Dr. Gamson was associated for a short period with the Armour Research Foundation, Chicago, and subsequently with the Socony Vacuum Oil Co. He has been with the Great Lakes Carbon Corp., since June, 1943. He received his Ph.D. from the University of Wisconsin.

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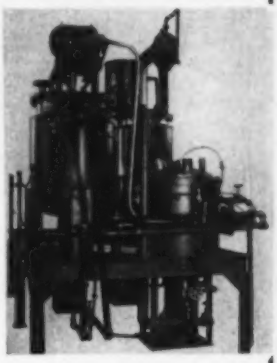

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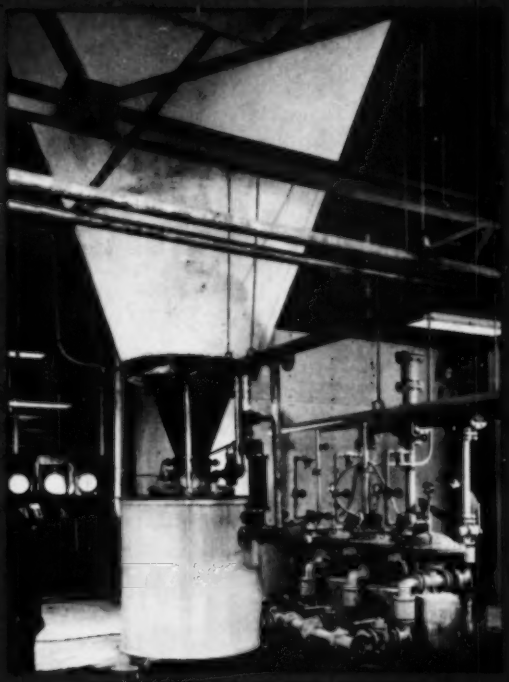

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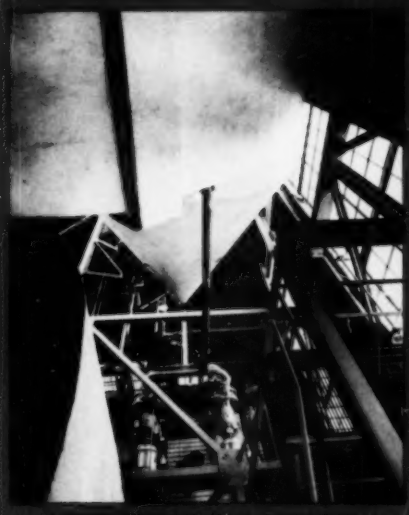

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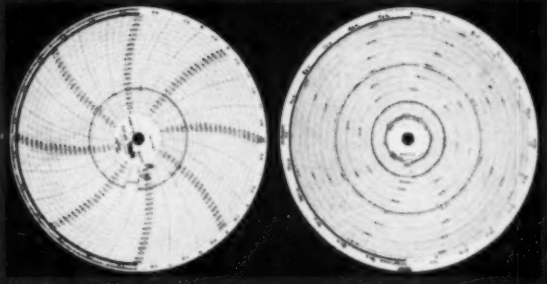

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